PB-251 292

AN IMPLEMENTATION PLAN FOR SUSPENDED PARTICULATE MATTER IN THE LOS ANGELES REGION

John Trijonis, et al

TRW, Incorporated

Prepared for:

Environmental Protection Agency

March 1975

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PB 251 292

AN IMPLEMENTATION PLAN
FOR
SUSPENDED PARTICULATE MATTER
IN THE LOS ANGELES REGION

FINAL REPORT

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
REGION IX - SAN FRANCISCO, CALIFORNIA

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

[illegible]

BIBLIOGRAPHIC DATA SHEET

1. Report No.

2.

3. Recipient's Accession No.

4. Title and Subtitle
Implementation plan for suspended particulate matter in the Los Angeles Region

5. Report Date
March 1975

6.

7. Author(s)
John Trijonis, George Richard, Kimm Crawford

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
TRW, INC.

10. Project/Task/Work Unit No.

11. Contract/Grant No.
1384
68-02-~~0304~~

12. Sponsoring Organization Name and Address
U.S. Environmental Protection Agency
Region IX
100 California St., San Francisco, CA 94111

13. Type of Report & Period Covered
final

14.

15. Supplementary Notes

16. Abstracts

This report presents the results of a study to develop a particulate implementation plan for the Metropolitan Los Angeles Air Quality Control Region. The Los Angeles Region presently experiences suspended particulate levels well in excess of the National Ambient Air Quality Standards. This study formulates control strategies which produce susbstantial reductions in suspended particulate levels and evaluates the impact of these strategies in 1977 and 1980. Because of the severity of the Los Angeles particulate problem and because of significant background particulate levels, the strategy for standard attainment is of a very drastic nature. This study formulates and recommends other less drastic control plans for actual implementation.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution control, California, Aerosols, Particulates, Emissions control, Costs.

17b. Identifiers/Open-Ended Terms

Los Angeles Air Quality Control Region, Ambient Air Quality Standards, Air pollution implementation plan

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page
UNCLASSIFIED

21. No. of Pages
261

22. Price
9.00-2.25

i.

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FINAL REPORT

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Prepared For

Environmental Protection Agency
Region IX - San Francisco, California

MARCH 1975

TRW/ TRANSPORTATION AND
ENVIRONMENTAL ENGINEERING
OPERATIONS

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1.0 INTRODUCTION

This report presents the results of a study, prepared under contract to the Environmental Protection Agency, to develop a particulate implementation plan for the Metropolitan Los Angeles Air Quality Control Region. The Los Angeles Region presently experiences suspended particulate levels well in excess of the National Ambient Air Quality Standards (NAAQS). This study formulates control strategies which produce substantial reductions in suspended particulate levels and evaluates the impact of these strategies in 1977 and 1980.

A principal goal of the present project is to identify a control strategy that will actually attain the NAAQS for particulates in the Los Angeles Region. Such a plan has been formulated and is described in the final chapters of this report. However, because of the severity of the Los Angeles particulate problem and because of significant background (non-controllable) particulate levels, the strategy for standard attainment is of a very drastic nature. Great socio-economic disruption and extreme implementation problems are inherent in the standard attainment strategy. Thus, this study formulates and recommends other (less drastic) control plans for actual implementation. These strategies do not attain the suspended particulate air quality standards, but they do achieve substantial improvement in particulate air quality. These alternative plans result in much more acceptable socio-economic costs and much more manageable implementation problems than the standard attainment strategy.

The present chapter serves as an overall introduction and summary for the study. The remainder of this section describes the organization of this report. Section 1.1 discusses basic definitions and establishes a consistent terminology. Section 1.2 deals with the limitations in scope which have been established for the project. In Section 1.3, the principal conclusions and recommendations of the study are reviewed.

Chapter 2 deals with basic technical background information. Before control strategies can be systematically formulated and evaluated, certain basic technical analyses must be performed. Chapter 2 summarizes the analytical foundation which has been established for this study. Three areas are covered: (1) analysis of particulate air monitoring procedures and characterization of present air quality levels in Los Angeles, (2) compilation of emission inventories and projections for both primary particulates and gaseous precursors of secondary particulates, and (3) development of a methodology to translate changes in emission levels into changes in air quality levels. More detailed descriptions of the technical analyses associated with each of these areas are found in Support Documents #1, #2, and #3 to this report, [1], [2], [3].

Chapter 3 presents alternative emission control measures for primary particulates and for gaseous precursors of secondary particulates. The emission reduction effectiveness, economic costs, and implementation problems associated with each measure are described. The control measures are organized according to both source type and pollutant type. Detailed data are presented for technological controls, but only qualitative discussions are given on non-technological (administrative) controls. Chapter 3 essentially consists of a summary of Support Document #4 which gives a more comprehensive analysis of the alternative control measures for various sources,[4] Chapter 4 describes and evaluates four alternative control strategy scenarios, each composed of various combinations of the control measures given in Chapter 3. The first strategy, called the "reasonable/implementable scenario", centers on a general policy of fuel desulfurization, along with some add-on controls for particulate and NO_x emissions. The second strategy consists of maximal technological controls for all sources. Strategy III is a delayed scenario, involving methanol conversion for stationary fuel conbustion sources and some add-on control measures. The final strategy combines the maximal technological controls with a drastic source relocation/VMT reduction scheme so as to provide for attainment of the particulate air quality standards. Each control scenario calls for the EPA oxidant implementation plan as a concurrent control for suspended particulates. For every strategy, an evaluation is made of emission reductions, air quality impact, economic costs, and implementation problems.

The final chapter presents conclusions and recommendations. These include control strategy conclusions as well as findings which have resulted from the technical support analyses. Some of the limitations inherent in the study are discussed, and areas for future work are briefly described.

1.1 BASIC DEFINITIONS

Suspended particulate air pollution in Los Angeles is an extremely complex phenomenon. Before embarking on a control study for this air pollution system, it is useful to establish agreement on terminology. This section provides definitions for several basic terms that appear frequently in this report.

In this study, suspended particulates and aerosol are used interchangeably. Both refer to suspended particles, (liquid or solid), in air.

The basic measuring unit used herein is total aerosol mass concentration, ($\mu g/m^3$); thus, the details of the particle size distribution are usually neglected.

One very important distinction that is made involves the concept of primary particulates versus secondary particulates, (or alternatively primary aerosol versus secondary aerosol).* Primary aerosols are directly emitted; they enter the atmosphere as particles. Secondary particulates are formed in the atmosphere from the conversion of gases to particles by chemical reaction processes. The four principal types of secondary aerosol are sulfate ($SO_4^=$), nitrate (NO_3^-), ammonium (NH_4^+), and secondary organics. The gaseous precursors of these aerosols are sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), and reactive hydrocarbons (RHC), respectively.

A distinction is sometimes made here, (see Section 2.1.1 or Support Document #1), between ambient total suspended particulates and Hi-Vol total suspended particulates. The former refers to total particulate mass loading in the atmosphere, while the latter refers to the mass loading which is measured by a Hi-Vol monitor. As discussed in Section 2.1.1, Hi-Vol measurements are sometimes not fully representative of ambient conditions.

A third distinction involves the concept of background particulates versus non-background particulates. For the purposes of this study, non-background aerosol is defined as that which is subject to direct emission regulations in the Metropolitan Los Angeles Region. Conversely, background aerosol consists of the part which is non-controllable by direct emission regulations in Los Angeles. In this sense, there are three main background aerosol sources: natural sources, suspended soil dust from man-related activities such as traffic or agriculture, and anthropogenic* sources exterior to the Metropolitan Los Angeles Region. This definition of background source differs from the more common usage which refers to natural sources only.

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*The reader should not confuse this concept with the terms "primary" and secondary" standards. The national primary and secondary standards refer to the different target levels for total particulate air quality, i.e. each standard applies to the sum of both primary and secondary aerosol.

In formulating control plans, it is useful to distinguish between control measures and control strategies. Herein, a control measure refers to a specific emission reduction technique applied to a certain source or group of sources. A control strategy consists of a collection of various control measures along with a timetable for implementation. Thus, the distinction between Chapters 3 and 4 of this report is that the former provides documentation on alternative control measures while the latter selects various combinations of these measures to formulate control strategy scenarios.

1.2 LIMITATIONS IN THE SCOPE OF THE STUDY

Limits in the allocated level of effort necessitated the establishment of certain bounds for this study. Countless decisions were made during the course of the project as to the depth of pursuit for various problems and issues. Some of the major limitations in study scope are discussed briefly below.

Study Region: The 4-County Sub-Area

As shown in Figure 1-1, the Metropolitan Los Angeles Air Quality Control Region includes all of Orange and Ventura Counties and portions of Los Angeles, Riverside, San Bernardino, and Santa Barbara Counties. During the course of this study, it was found that suspended particulate levels in Ventura and

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*Man-made

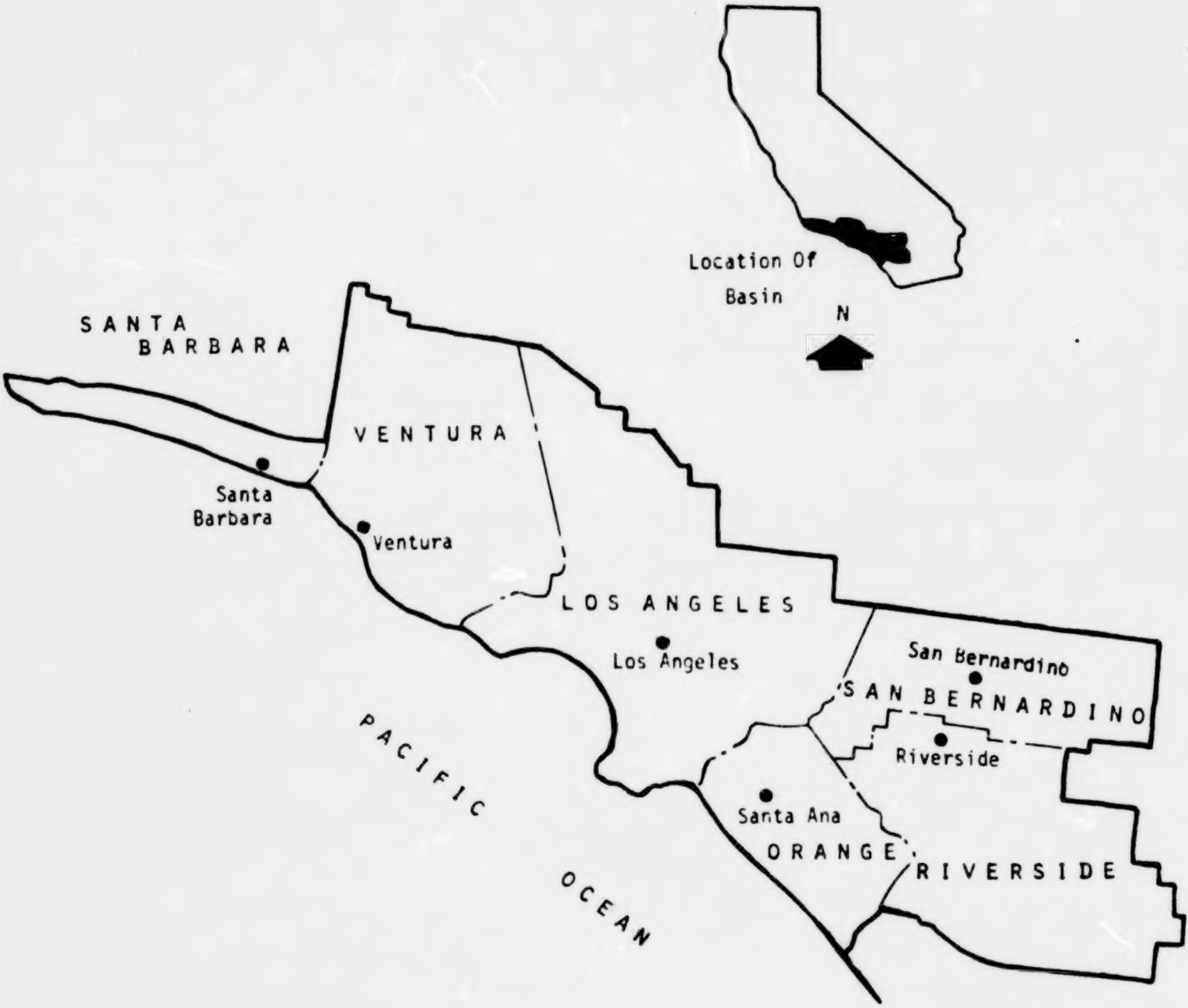
Location Of Basin
N
SANTA BARBARA
VENTURA
Santa Barbara
Ventura
LOS ANGELES
Los Angeles
San Bernardino
SAN BERNARDINO
Riverside
Santa Ana
ORANGE
RIVERSIDE
PACIFIC
OCEAN

Figure 1-1 Metropolitan Los Angeles Air Quality Control Region

Santa Barbara Counties are generally much lower than levels found in the other four counties, (the 4-County Sub-Area). The highest annual readings in Ventura and Santa Barbara Counties are very close to the primary national standard for suspended particulates, (75 $\mu g/m^3$ AGM), while the highest readings in the other four counties are well in excess of that standard sometimes by a factor of two or more. Also, the overall emission and meteorological patterns in the Los Angeles Region support the conclusion that sources in Ventura and Santa Barbara Counties have negligible impact on overall air quality levels in the 4-County Sub-Area. In an air quality sense, the 4-County Sub-Area can be viewed as a distinct entity within the entire air basin. In this study it was decided to focus on the 4-County Sub-Area in formulating and evaluating control strategies.

Annual Versus 24-Hour Standards

Federal air quality standards for suspended particulates have been established for both long term (annual geometric mean) and short term (24-hour maximum) concentrations. However, in evaluating the impact of control strategies on air quality, this study focuses only on the annual levels. There are two basic reasons for this restriction in scope. First, analyses performed in this study indicate that the annual standards are the binding constraints for the Los Angeles Region. Attainment of the annual standards apparently implies concurrent attainment of the 24-hour standards. Second, it was found that existing aerometric data could not support a sound emission level/air quality model for 24-hour concentrations. In contrast, data were sufficient to allow a systematic model for annual particulate levels. A detailed discussion of these two reasons can be found in Section 2.1 of Support Document #3 to this study.

Strategy Time Frame and Base Year Selection

As called for by contractual arrangements with the Environmental Protection Agency, this study evaluates control strategies for the years 1977 and 1980. Although quantitative analyses are not carried out for post 1980, some of the qualitative long term differences between alternative strategies are discussed.

The base year for the study is 1972. This choice is convenient in the sense that it is the most recent year for which both extensive emission and air quality data are available. The base year emission data are used as the foundation for emission forecasts to 1977 and 1980. Both the emission and air quality data for the base year are important as calibration parameters for an air-quality/emission-level model.

It should be noted that this report treats base year air quality in a statistical sense. "Expected" 1972 air quality levels are determined from the statistical distribution of particulate levels based on two years of data (7/71-6/73) and from a comparison of these results to several more years of data. These expected levels, rather than actually measured 1972 levels, are used to characterize air quality for the base year. This helps to avoid the pitfall of calibrating the air quality model with an anomalous measured air quality value which may have occurred in the base year.

Particulate Size Distribution and Chemical Composition

The objective of this study is to investigate control strategies for approaching and/or attaining the national air quality standards for particulates. These standards are specified in terms of the total mass concentration of suspended particulates, ($\mu g/m^3$). The usage of only total mass concentration neglects the size distribution and chemical composition of particulate matter. The particulate size distribution is a very important factor for public health and visibility considerations. Light scattering is much more efficiently produced by particles in the .1 to 1 micron size range than by an equivalent mass of particles outside that range. Sub-micron particles have also been shown to be relatively more deleterious to pulmonary health than larger particles. The chemical pomposition of particulates, (e.g. sulfate, lead, asbestos, etc.), is also a very important factor in health effects.

The only parts of this study which treat particle size distribution in a specific and quantitative way are the emission inventory and control effectiveness analyses for primary particulates. In the inventory, emitted total particulates are distinguished from emitted suspended particulates. The distinction is based on a particle diameter of 10 microns, (only those smaller than 10 microns are considered as suspended). The efficiency of various control measures for primary particulate emissions are also computed separately for total and for suspended emissions. The emissions and control data for suspended particulates are used in calculating air quality changes resulting from emission level changes.

The chemical composition of particulate matter is considered here in order to formulate an air quality model for suspended particulates. Changes in air quality levels are computed separately for sulfates, nitrates, ammonia, secondary organics, and primary particulates.* The complete change in suspended particulate air quality is calculated by summing the changes for the individual categories. Since this study is concerned with the existing national standards, only the results for total suspended particulate air quality are presented. One exception is made in Chapter 5, where the impacts of alternative strategies on sulfate levels are also briefly discussed.

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*Data are also available in this study for determining the effect of lead emissions on suspended lead air quality.

1.3 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS:

Chapter 5 of this report presents the conclusions and recommendations that have resulted from this investigation. For summary and emphasis, the most significant points are listed below.

Conclusions:

- For the purpose of control strategy formulation, at least three general sub-areas of the Los Angeles Region have been identified, each with different maximal suspended particulate levels, (the maximum among the monitoring sites in those areas). These are 1) Ventura and Santa Barbara Counties (presently just above the national primary standard), 2) the Four-County Area except Area 3 below (presently at about twice the national primary standard), and 3), the Western San Bernardino County Hot-Spot (presently at about three times the national primary standard).
- Eight process categories account for more than 97% of primary suspended particulate, SO_2,NO_x, and RHC emissions in the Los Angeles Region. They are stationary fuel combustion, motor vehicles, the petroleum industry, aircraft, the chemical industry, metallurgical processes, organic solvent use, and mineral processes. The first four categories are especially significant. Motor vehicles are the major source of RHC and NO_x emissions in the 1972 base year inventory. Motor vehicles, stationary fuel combustion, and aircraft account for most of the suspended particulate emissions. Stationary fuel combustion, chemical

processes, petroleum refineries, and motor vehicles, respectively are the most important sources of SO_2.

- The forecasted substitution of fuel oil for natural gas in stationary combustion sources and the scheduled controls for motor vehicles are the two most significant factors affecting emission projections for 1977 and 1980 in the Los Angeles Region. Due to the increased use of fuel oil, basin-wide emissions of suspended particulates, SO_2 and NO_x will increase from 1972 to 1977 with present control policies. The motor vehicle control program will significantly reduce regional RHC emissions in 1977 and 1980, especially if the EPA oxidant implementation plan is implemented. Around the middle of the decade, motor vehicle controls will reverse the upward trend in regional NO_x emissions. The combined effect of these emission trends leads to very slight changes in air quality from 1972 to 1977 and 1980. Suspended particulate levels are forecasted to increase marginally at most locations; however, a few sites will experience minor improvements in air quality.

- Existing data indicate that background (noncontrollable) particulate levels are around 30-40 ug/m^3 AAM in the coastal areas of the Los Angeles Region. Background aerosol levels apparently increase with distance inland to about 45-60 ug/m^3 AAM in the eastern-inland parts of the region. The existence of substantial background levels limits the air quality effectiveness of emission controls in the Los Angeles Region; a very high degree of control for man-made sources will be required to attain the national air quality standards.

- Non-background primary particulate contributions generally tend to be highest in the coastal and central-valley areas of the Los Angeles Region. The one exception involves the Western San Bernardino County Hot-Spot (Chino-Rialto) which is apparently influenced by the Kaiser Steel/Edison Electric complex. Sulfate levels tend to be uniformly distributed over the basin at around 10-15 $\mu g/m^3$ AAM, (again the Hot-Spot is an exception). Measured nitrate and estimated secondary organic levels tend to increase considerably with distance inland. The combined effect of background and non-background spatial patterns is a slight general increase in total suspended particulates with distance inland. The above spatial air quality trends are consistent with known aspects of emission source distribution, meteorology, and atmospheric chemistry.

- The federal and state motor vehicle controls and the county APCD stationary source programs have achieved substantial overall levels of control for primary particulates and gaseous precursors of secondary particulates in the Los Angeles Region. The most significant additional technological control alternatives for primary suspended particulates are motor vehicle particulate traps, fabric filters, electrostatic precipitators, and alternative fuels (e.g. methanol). The major additional control possibilities for SO_2 are desulfurization of petroleum products to very low sulfur levels, SO_2 removal processes for exhaust gases, and alternative fuels, For further NO_x control, modifications of combustion processes and alternative fuels are the principal control measures. The EPA oxidant plan appears to incorporate all the major additional RHC control options that are presently implementable. Non-technological control options include growth restrictions, relocations, and source usage measures (e.g. conservation policies or transportation controls).

- Application of the most effective technological controls which have been identified in this study will attain overall reductions of 59%, 86%, and 22% (for primary suspended particulates, SO_2, and NO_x respectively) from projected 1977 levels. Since emissions of each pollutant are projected to increase from 1972 to 1977, the overall reductions in 1977 from 1972 levels are only 49%, 83%, and 6% respectively. The EPA oxidant plan will achieve a 51% reduction in RHC levels from 1972 to 1977.

Recommendations:

- A strategy to attain the national primary standards for suspended particulates in the Los Angeles Region would involve severe non-technological controls in addition to the maximum degree of technological control available from measures considered in this study. The overall degree of non-technological control required would be equivalent to 75% relocation of aircraft activity, power plants, refineries, and major industrial sources plus a 50% reduction in motor vehicle traffic. Because of the great socio-economic disruptions and implementation problems involved, the standard attainment strategy is not recommended as a viable basis for air quality control policy in the 1970's.
- Two alternative technological control strategies are recommended as options for suspended particulate air quality policy in the 1970's. One is based on desulfurization of fuels plus add-on devices for various sources. The second is a delayed scenario emphasizing methanol conversion for stationary combustion sources plus add-on devices for other sources. Although neither strategy will produce standard attainment at all locations by 1980, significant air quality improvements are attained by each. The annualized cost for the strategies is about $230 million per year. The methanol strategy leads to a three year delay in air quality improvement and entails greater implementation problems; however, we find a slight preference for it based on long term advantages for air quality and energy considerations. In general, long term strategies seem more appropriate than

shorter term approaches due to the expected long term nature of the particulate air quality problem in the Los Angeles Region.

- It is recommended that growth restrictions, energy conservation measures, and transportation controls be given further study. Appropriate non-technological controls should be combined with the proposed technological strategies to form a more comprehensive air quality control plan.
- The particulate air pollution problem in the Los Angeles Region will be aggravated by the forecasted substitution of fuel oil for natural gas in stationary combustion sources. It is recommended that national allocation of clean fuels, such as natural gas, be performed with strong consideration given to relative air quality impacts in various regions.
- The technical support analyses for this study encountered many areas of uncertainty due to inadequacies in existing data. Recommendations for future work to help reduce these uncertainties are made in Chapter 5 of this study.

2.0 BASIC TECHNICAL BACKGROUND INFORMATION

The purpose of the present study is to formulate an implementation plan for the control of suspended particulates in the Metropolitan Los Angeles Air Quality Control Region for the years 1977 and 1980. In order to formulate this plan, certain preliminary analyses are required which serve as basic technical supports for the study. First, existing air monitoring data must be analyzed so that base year (1972) particulate air quality can be characterized for the Los Angeles Region. This characterization establishes the overall scope of the problem and helps to identify sub-areas of the region for the purpose of control strategy formulation. Second, emission inventories and projections must be compiled for primary suspended particulates as well as for the gaseous precursors of secondary particulates. The 1972 base year emission inventories and the 1972 air quality characterization serve as the fundamental calibration parameters for an air-quality/emission-level model. The emission projections to 1977 and 1980 are for the existing or nominal control policy; the control strategies proposed later will be applied to this projected inventory. Finally, a model must be formulated which can translate emission level changes into air quality changes. This model is used to project air quality for the existing or nominal control policy and later to determine the air quality impact of the control strategies proposed in the implementation plan.

The above three preliminary studies have been performed as described in the first three Support Documents to this report, [1], [2], [3]. This chapter serves to summarize the results. Section 2.1 deals with the analysis of particulate air monitoring data. Section 2.2 presents the emission inventories and projections. In Section 2.3, a model is described for determining the air quality impact of emission level changes.

2.1 ANALYSIS OF AIR MONITORING DATA

The first preliminary technical study, (Support Document #1), consists of an analysis of Hi-Vol monitoring data for the Metropolitan Los Angeles Region. The main objective of this analysis is to characterize particulate levels in the Los Angeles Region for the 1972 base year. This characterization is presented below in Section 2.1.3.

In using ambient measurements to characterize air quality, it is important to know what those measurements represent and how they were taken. This helps to establish error bounds for the air quality characterization. Accordingly, two sub-objectives of the air monitoring data analysis are to review the Hi-Vol monitoring method in general, and to review the procedures of Los Angeles Region monitoring programs in particular. These reviews are presented in Sections 2.1.1 and 2.1.2 below.

2.1.1 Review of the Hi-Vol Sampling Method

The National Ambient Air Quality Standards for suspended particulates specify Hi-Vol sampling as the appropriate monitoring technique. The official procedure is published in the Federal Register, [5]. Comprehensive descriptions of the Hi-Vol monitoring technique are found in References [6] and [7].

A Hi-Vol sampler (illustrated in Figure 2-1) consists of a covered housing, a filter holder assembly, a vacuum sweeper motor, and a flow meter. Sampling with a Hi-Vol basically consists of weighing a preconditioned (temperature and humidity) filter pad, drawing air through the pad for a given time (usually 24 hours), recording the initial and final flow rates, and reweighing the pad (again after con-

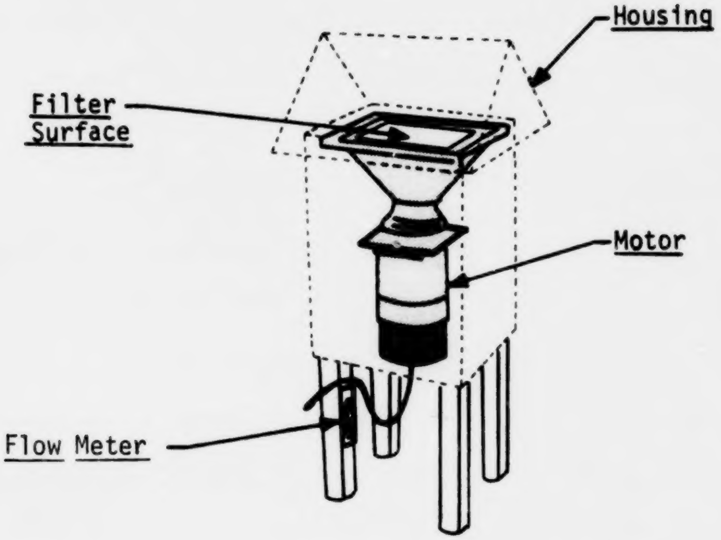

Figure 2-1 Hi-Volume Sampler and Shelter

ditioning to set humidity and temperature). The average concentration of total suspended particulates is calculated by dividing the weight gain of the filter pad by the total volume of air sampled.

Hi-Vol filters generally provide a very efficient means of entrapping samples of suspended particulates. The filter fibers tend to intercept larger particles (>1 Micron) by mechanical action and smaller ones (<0.1 Micron) by Brownian motion. A minimum in collection efficiency is observed in the 0.1 to 1 Micron range. However, the EPA reference procedure calls for filter standardization to achieve 99% collection efficiency at a nominal particle diameter of 0.3 Microns. This level of collection in the range of minimal efficiency insures an extremely high overall entrapment efficiency.

The high level of collection efficiency does not insure that Hi-Vol samples accurately represent ambient particulates. Factors other than entrapment efficiency are important. Volatile liquid aerosols can be lost during the sampling and analysis procedures, leading to an underestimate of true, ambient aerosol mass. Gaseous pollutants, particularly SO_2 and NO_2 can be adsorbed on the filter, leading to an overestimate. Measurement techniques for air volume and mass deposit are also potential sources of inaccuracy. As will be discussed below, the importance of these various factors depends on the nature of the test atmosphere and on the specific monitoring procedures which are practiced. However, in terms of a gross generalization, the potential error in a Hi-Vol measurement typically appears to be on the order of 10 to 20%.

Factors Affecting Hi-Vol Accuracy

Aspects of Hi-Vol monitoring practice which affect sampling accuracy are the choice of filter media, equilibriating procedures, flow measurement techniques, calibration procedures, and weight and time measurements. These will be discussed very briefly here. A more detailed treatment can be found in Support Document #1 to this study, [1].

Routinely, Hi-Vol sampling is performed with glass fiber filters. The principal advantages are; high collection efficiency, low flow resistance, and low tendency to plug under heavy loading. One disadvantage is that some alkalinity may be associated with the glass, resulting in adsorption of acid gases such as SO_2 and NO_2 and leading to an apparent increase in measured particulate loading. The magnitude of this error depends on the chemical nature of the test atmosphere.

To minimize this effect, acid washed filters are preferred.

To obtain reproducible results with Hi-Vol samples, weighing of filter pads is performed after conditioning at controlled humidity and temperature. The standard equilibriating procedures call for 50% RH and 20°C. Present evidence indicates that equilibrated Hi-Vol data reflect only trace amounts of water, [8], [9]. This apparently represents an understatement of ambient loadings which can contain water fractions of 10-20%, or more, [10]. Volatile organic material associated with the particulate phase also may evaporate between sampling and weighing, [11], [12]. The magnitude of this effect depends on the amount of organic material present, but the typical impact on total measured particulate mass should not exceed a couple percent, [11]. A short delay between sampling and weighing will help to reduce this source of error.

Flow measurement techniques and flow meter calibration procedures are important factors in the precision of Hi-Vol measurements. With the continuous flow measurement technique and with frequent calibrations, the accuracy of flow measurements should be about ± 5%, [11], [13]. Using an average of initial and final flow readings or performing infrequent calibrations can increase the potential error by a factor of 2 or more.

Weight and time measurement techniques are a relatively small source of error in Hi-Vol data. The uncertainty in these techniques is typically less than ± 1%.

Reproducibility of Hi-Vol Measurements

Investigators have examined the overall reproducibility of

Hi-Vol measurements under a variety of operating conditions, [7], [14], [15], [16], [17], [18]. These studies suggest that, for given monitoring procedures, the reproducibility of Hi-Vol measurements varies from about ± 2% under carefully controlled conditions to about ± 6% under actual field conditions. It should be remembered, however, that reproducibility does not necessarily represent accuracy. As noted above, Hi-Vol monitoring procedures can contain built-in biases which result in consistent underestimates or overestimates of ambient aerosol loadings.

Chemical Analysis Procedures

After Hi-Vol samples have been weighed to determine total aerosol mass, the filters can be divided up for analysis of metals, inorganic ions, and/or organic material. Support Document #1 to this study describes some of the chemical analysis procedures involved. It appears that current methods for metals and inorganic ions are generally appropriate; the precision of these methods is around ± 10%.* In contrast, the common analysis procedures for organics are notably deficient. Measurements of organic aerosol content typically consist of data on benzene solubles, (or sometimes cyclohexane solubles). Benzene and cyclohexane are fairly efficient for extracting primary organic aerosol, e.g., the tarry particles emitted in auto exhaust. However, both solvents are very inefficient for highly oxidized secondary organic compounds; possibly 30% or less of the secondary organic aerosol is extracted, [19], [20]. For areas like Los Angeles, where secondary organic aerosol contributions are very significant, benzene or cyclohexane solubles provide a poor measure of organic particulate levels.

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* A notable exception involves some lead data determined by the "ash procedure". Before the ash procedure was standardized, values for lead were often 50% or more low due to excessive temperature and baking time.

Hi-Vol Sampler Location

Hi-Vol measurements are sensitive to the details of sampler location. Since larger particles have a lower probability of being transported to higher elevations, total particulate loading tends to decrease with height. The proximity to local sources, such as traffic, also has a strong affect on measured particulate levels. Recent data taken in Los Angeles indicate about a 20% decrease in Hi-Vol measurements from an elevation of 20 feet to an elevation of 90 feet, [1].

Several guidelines are pertinent to Hi-Vol sampler location

- Hi-Vol sampling should be performed at 50 feet or less above ground in order to represent prime human exposure areas.
- Samplers should be located away from direct influence by local particulate sources.
- Pairs of Hi-Vols should be several feet apart to avoid sampling each other's exhaust.
- The exhaust should be two or more feet above ground to avoid stirring up ground dust.
- Sampling should be done away from a wall to allow representative air to pass over the monitor.

Compliance with these guidelines should be checked when using Hi-Vol data for air quality analysis.

2.1.2 Review of Monitoring Programs in the Los Angeles Region

There are three major sources of Hi-Vol data in the Metropolitan Los Angeles Region: the Air Pollution Control Districts (APCD's), the National Air Surveillance Network (NASN), and the Community Health Environmental Surveillance System (CHESS). The APCD's are county agencies, while NASN and CHESS are federal programs. Table 2-1 summarizes the number of sampling sites and the sampling frequency for each of the monitoring programs. Figure 2-2 illustrates the location of the Hi-Vol sites within the Los Angeles Region.*

TABLE 2-1 SAMPLING SITES AND SAMPLING FREQUENCY OF THE APCD, NASN, AND CHESS MONITORING PROGRAMS IN THE LOS ANGELES REGION

MONITORING PROGRAM	NUMBER OF SAMPLING SITES	SAMPLING FREQUENCY
County APCD's		
Los Angeles	6	~70 per year
Orange	3	~90 per year
San Bernardino	7	~60 per year
Riverside	1	~70 per year
Ventura	10	~60 per year
Santa Barbara	1	~60 per year
Total - APCD's	28	60 - 90 per year
NASN	11	~24 per year
CHESS	6	daily

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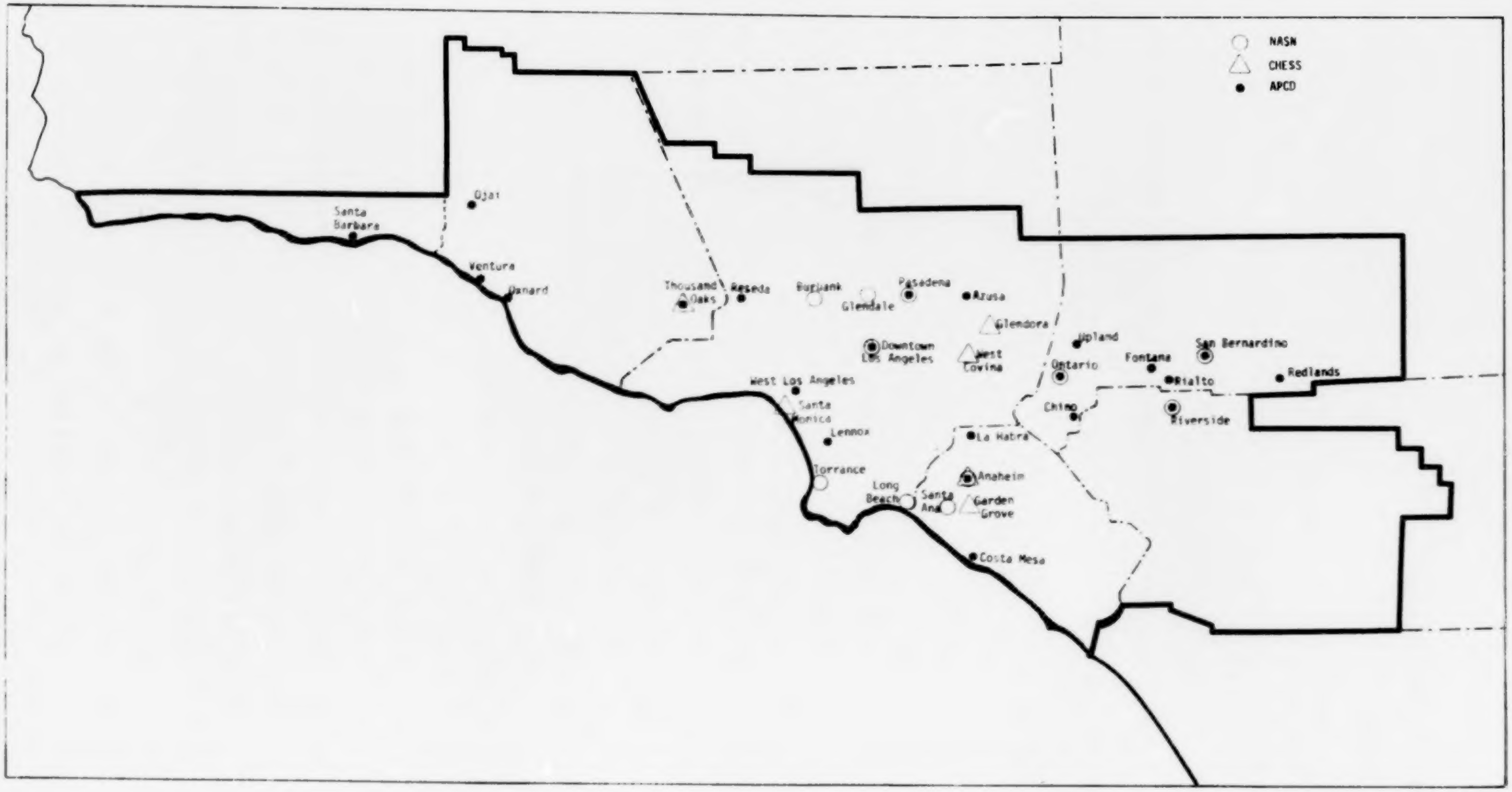
* The addresses of the sampling sites are presented in Support Document #1 to this study, [1].



NASN
CHESS
APCD
Santa Barbara
Ojai
Ventura
Oxnard
Thousand Oaks
Reseda
Burbank
Glendale
Pasadena
Azusa
Glendora
Downtown Los Angeles
West Covina
West Los Angeles
Santa Monica
Lennox
Torrance
Long Beach
Santa Ana
La Habra
Anaheim
Garden Grove
Costa Mesa
Upland
Ontario
Chino
Fontana
Rialto
San Bernardino
Redlands
Riverside

Figure 2-2. APCD, NASN, and CHESS Hi-Vol Sites in the Metropolitan Los Angeles Region

Comparison of Monitoring Procedures

Support Document #1 reviews the specific Hi-Vol monitoring procedures of the APCD, NASN, and CHESS programs, [1]. As discussed later in Section 2.1.3, this review is useful in deciding what data to rely on in characterizing air quality levels in the Los Angeles Region. Some of the more significant results of the monitoring program review can be summarized as follows:

- Sampling in the CHESS program is performed daily. Sampling frequencies of the various county APCD's range from every fourth to every ninth day. NASN Hi-Vol measurements are taken only about twice a month.
- Non-acid washed glass fiber filters are used in each monitoring program. Equilibriation at 20°C and 50% RH is performed by all agencies except the Ventura County APCD. All agencies except the Los Angeles County APCD use the orifice plate calibration method.
- Uniform sampler positioning guidelines do not appear to have been enforced in either the NASN or APCD programs. NASN and APCD samplers are at heights varying from ground level to about 100 feet, but most of the APCD monitors are at 10-30 feet elevations.
- CHESS monitors tend to be located in quiet areas such as suburban school yards. NASN stations in Los Angeles generally represent downtown commercial areas. Most APCD monitors are also in commercial areas.
- The most extensive data on Hi-Vol chemical composition are provided by the NASN, Los Angeles APCD,

and San Bernardino APCD programs. The Ventura, Orange, Riverside, and Santa Barbara APCD's take either no composition data or data on lead only.

Comparison of Measured Hi-Vol Levels

Table 2-2 provides an overall comparison of APCD, NASN, and CHESS measurements for total suspended particulates in the Los Angeles Region. The available annual geometric means (AGM's) are given for 1967 through 1973. The main point emphasized by Table 2-2 is that the CHESS values are considerably lower than APCD or NASN values in each of the three counties with CHESS stations. For instance, Los Angeles County data typically fall in the range of 75-155 $\mu g/m^3$ for APCD samples and 75-130 $\mu g/m^3$ for NASN samples. However, CHESS data in Los Angeles county are in the range of 50-100 $\mu g/m^3$. The apparent reason for this discrepancy is that the CHESS data represent residential areas rather than prime exposure areas. CHESS sites have been chosen for a health study involving school children, and, as discussed above, they are located in quiet suburban areas, [21].

The overall Hi-Vol levels measured by the NASN and APCD programs appear to be generally in line with one another. To examine the question of agreement more rigorously, statistical "t" tests were performed for five locations where NASN and APCD monitors have been maintained within a few years of one another. Table 2-3 summarizes the results. County APCD data are slightly higher than NASN data at Riverside, San Bernardino, and Ontario, but the differences are not statistically significant to 95%. At Anaheim, APCD data are lower

TABLE 2-2

APCD, NASN, AND CHESS ANNUAL HI-VOL LEVELS, AGM'S FOR 1967 - 1973

COUNTY APCD STATIONS

County	Station	1973	1972	1971	1970	1969	1968	1967
Los Angeles	Central LA	114	130	162	136	164	157	145
	Lennox	124	137	154	144	150	148	139
	W.Los Angeles	74	86	85	91	99	92	71
	W.San Fernando Valley (Reseda)	103	143	115	112	117	109	135
	Azusa	121	150	138^C	-	-	-	-
	Pasadena	101	110	106^C	-	-	-	-
Riverside	Riverside	135^D	140^D	(136^D)	-	-	-	-
San Bernardino	San Bernardino	85	108	117	119	91	121	123
	Ontario	88	110	111	107	134	151	122
	Redlands	89	96	94	102	94	95	133
	Fontana	111	136	100	NA	NA	NA	109
	Rialto	153	170	130	139	NA	151	NA
	Chino	118^B	194	178	NA	172	163	144
	Upland	127	-	-	-	-	-	111
Orange	Anaheim	98	105	85	95	105	95	NA
	La Habra	113	120	114	-	-	-	-
	Costa Mesa	66	67	-	-	-	-	-
Ventura	Oxnard	77	77	71	64	-	-	-
	Ojai	66	66	73	-	-	-	-
	Santa Paula	67	76	-	-	-	-	-
	Ventura	73	66	69	51	-	-	-
	Camarillo	80	73	90	-	-	-	-
	Port Hueneme	106	97	-	-	-	-	-
	Simi Valley	74	-	-	-	-	-	-
	Moore Park	62	-	-	-	-	-	-
	Pt. Mugu	58	-	-	-	-	-	-
	Thousand Oaks	81	-	-	65	92	-	-
Santa Barbara	Santa Barbara [A]	NA	66	60	-	-	-	-

NASN STATIONS

Los Angeles	Central LA	NA	120	133	125	93	129	91
	Pasadena	NA	90	100	111	90	106	-
	Burbank	NA	117	131	123	88	103	-
	Glendale	NA	95	85	87	74	90	75
	Long Beach	NA	96	87	95	104	114	118
	Torrance	NA	73	88	86	68	-	-
Riverside	Riverside	NA	114^E	120	119	124	116	-
San Bernardino	San Bernardino	NA	135	104	118	95	92	-
	Ontario	NA	117	111	116	109	116	-
Orange	Anaheim	NA	103	116	114	93	-	-
	Santa Ana	NA	96	140	127	123	95	-

CHESS STATIONS

Los Angeles	Santa Monica	67	69	-	-	-	-	-
	Glendora	48	97	-	-	-	-	-
	West Covina	64	99	-	-	-	-	-
Orange	Anaheim	67	87	-	-	-	-	-
	Garden Grove	63	80	-	-	-	-	-
Ventura	Thousand Oaks	35	59	-	-	-	-	-

A California ARB Data

B Station Moved from Airport to Downtown Chino after 1972

C Represents July to December only

D Calculated from raw data of Riverside APCD

E 3 Quarters only

than NASN data, and the difference is just over 95% significant. At Central Los Angeles, APCD data are much higher than NASN data and the results are very significant on a statistical basis. As discussed in Support Document #1, the discrepancy at Anaheim may best be assigned to less frequent calibration of the NASN samplers, [22]. The one very large discrepancy, at Central Los Angeles, may be due to differences in calibration procedures and/or to a higher operating flow rate for the NASN Hi-Vol, [9].

TABLE 2-3 EQUIVALENCY TESTS FOR APCD AND NASN HI-VOL GEOMETRIC MEANS

LOCATION	YEARS OF DATA	GEO. MEAN LEVELS ($\mu g/m^3$)		"t" VALUE
		APCD	NASN	
Central Los Angeles	1967-1972	147	114	6.5
Riverside	1970-1971	136	121	1.6
San Bernardino	1968-1972	111	108	0.5
Ontario	1968-1972	121	114	1.1
Anaheim	1969-1972	97	106	2.1

NOTE: t = 1.98 for 95% confidence of a statistical difference in the respective data

2.1.3 Characterization of Hi-Vol Levels in the Los Angeles Region for the 1972 Base Year

The main objective of the present section, ANALYSIS OF HI-VOL AIR MONITORING DATA, is to characterize Hi-Vol air quality in the Los Angeles Region for the 1972 base year. This characterization will provide a systematic comparison of present Hi-Vol levels at various locations in the Los Angeles Region to the National Ambient Air Quality Standards for particulates, (presented in Table 2-4). The comparison will be used here to define sub-areas of the Los Angeles Region for the purpose of control strategy formulation. Later, in Section 2.3, the 1972 air quality characterization will serve as a fundamental calibration input for an air-quality/emission-level model for particulates in the Los Angeles Region.

TABLE 2-4 THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATES

	Annual Geometric Mean	Maximum: Not to be exceeded more than once a year
PRIMARY STANDARD	75 $\mu g/m^3$	260 $\mu g/m^3$ for 24 hours
SECONDARY STANDARD	60 $\mu g/m^{3*}$	150 $\mu g/m^3$ for 24 hours

*Target level for achievement of the secondary 24 hour standard

Policies for Data Analysis

In characterizing present Hi-Vol levels for Los Angeles, two main policy issues arose concerning data analysis. The first issue involves the question of which data set to emphasize, i.e., APCD data vs. NASN data vs. CHESS data. As noted in the previous section, these data sets are not totally consistent. The decision was made to rely basically on APCD data, using NASN and CHESS data as supports where appropriate. The reasons for emphasizing APCD data are summarized below:

- CHESS data tend to represent "clean urban" areas and are considerably lower than APCD data which in many cases represent "prime exposure" areas. The use of APCD data will provide a more conservative comparison of present air quality to the air quality standards. The addition of the 6 CHESS sites to the 28 APCD sites adds no further binding constraints in designing control strategies to meet the air quality standards.

- APCD samples are taken more frequently than NASN samples; thus, they provide a better statistical data base. APCD Hi-Vols are usually standardized more frequently than NASN samplers. There is a shorter time period between sampling and weighing for APCD samples. Also, several NASN sites are higher above ground than recommended.
- For the areas with the highest Hi-Vol recordings, APCD results appear to be somewhat higher than NASN results, (although the difference is statistically very significant only at Central Los Angeles). The addition of 11 NASN sites to the 28 APCD sites adds no further constraints on the degree of reduction required by control strategies in order to attain the NAAQS.

The second issue involves the statistical treatment of the data. In many previous implementation plans for various pollutants, base year air quality has simply been taken as the air quality level actually measured in the base year, e.g., the actual annual average or actual one day maximum that occurred in the base year. Unfortunately, an anomalous value in the base year can have pronounced effects on the degree of control required in the implementation plan. With APCD Hi-Vol data, the potential for a very uncharacteristic value to occur in any given year is significant; sampling is performed only 60-90 days per year and the standard deviations of the measured annual geometric means are ± 10 to 15%.

To account for the stochastic nature of air quality levels, it was decided in this study to perform a statistical examination of Hi-Vol levels in the Los Angeles region. The basic statistical tool involved the use of "log-probability" paper. The techniques which were used are explained in detail in Support Document #1, [1]. Basically, Hi-Vol data were plotted on log probability paper and straight lines, (log normal distributions), were fitted to the data. The expected annual geometric mean and expected 24 hour maximal values were calculated from these distributions.

To augment the amount of data for determining the 1972 base year Hi-Vol distributions, measurements were used for the period of July 1971 to June 1973, (2 years of data).* The distributions were determined for the 15 APCD monitoring sites listed in Table 2-5. The two main criteria in selecting these sites were that they be scattered throughout the air basin and that they be the sites with maximal Hi-Vol levels for the particular sub-area which they represented. The log-normal plots and relevant statistical parameters for each of the 15 Hi-Vol sites are presented in Support Document #1 .

Expected Annual Geometric Means for the 1972 Base Year

Figure 2-3 presents the expected annual geometric mean Hi-Vol levels for the 1972 base year at the 15 APCD monitoring sites listed in Table 2-5. As noted above, these expected AGM'S have been calculated from statistical distributions based on data from 7/71 to 6/73.

To check that the period from 7/71 to 6/73 was not an extremely unusual meteorological period for Hi-Vol geometric means, the calculated values were compared to historical AGM'S (from 1967-1973) in Support Document #1, [1]. This check indicated that the values in Figure 2-3 were generally in agreement with the historical record. **

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* For two locations, slightly different periods were used because the monitoring sites were changed during 7/71 to 6/73. See Support Document #1 for details, [1].

** The only notable exceptions were that the Reseda (and possibly Azusa) value might be about 10% higner than for average meteorology and the Central Los Angeles value might be about 10-15% lower than for average meteorology.

TABLE 2-5 MONITORING SITES FOR THE 1972 BASE YEAR AIR QUALITY CHARACTERIZATION

LOS ANGELES COUNTY	Lennox Central Los Angeles Reseda West Los Angeles Pasadena Azusa
ORANGE COUNTY	La Habra Anaheim
San Bernardino County	San Bernardino Ontario Chino Rialto
Riverside County	Riverside/Rubiodoux
VENTURA COUNTY	Oxnard
SANTA BARBARA COUNTY	Santa Barbara

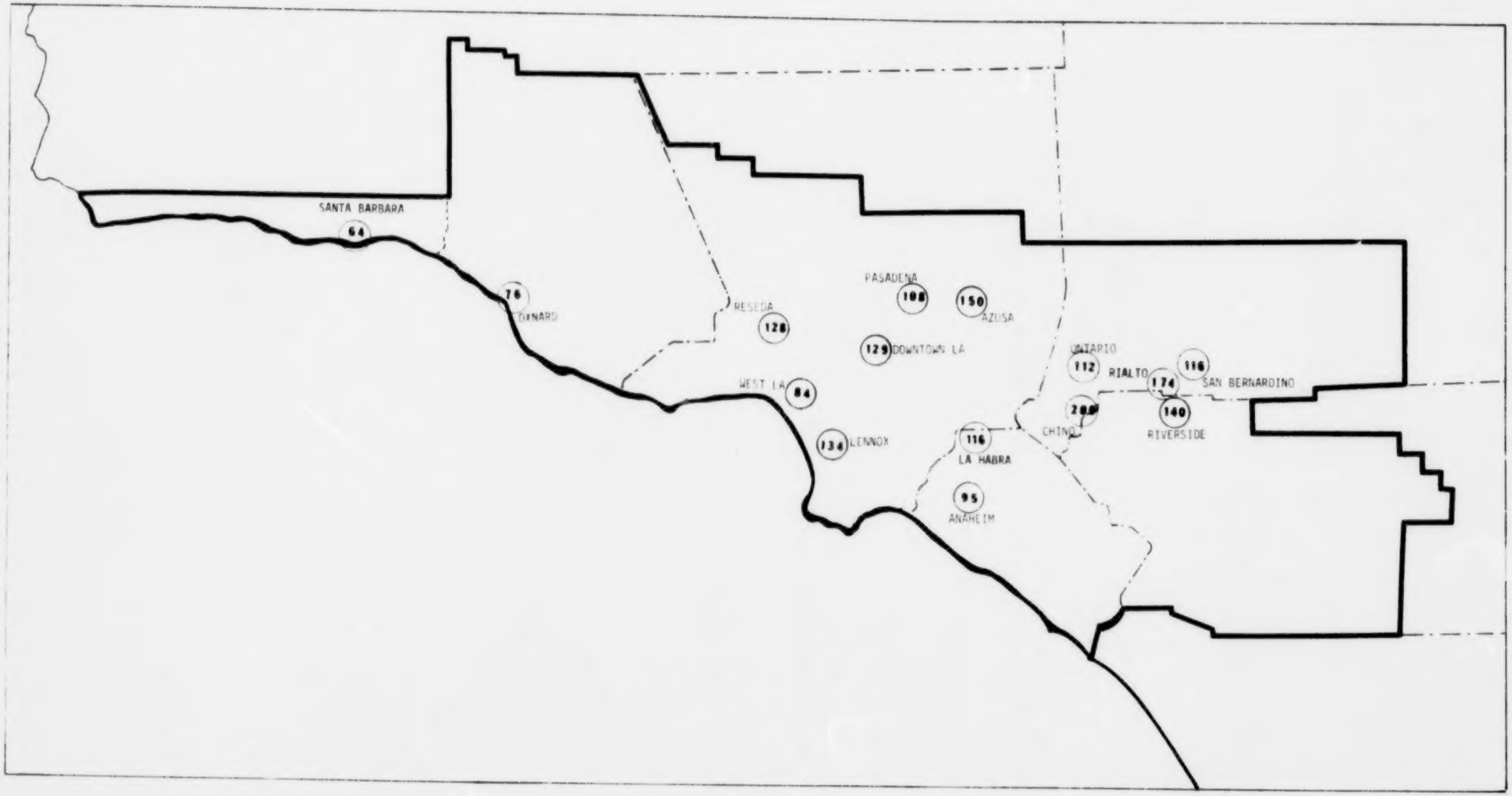

SANTA BARBARA
64
76
OXNARD
RESEDA
128
PASADENA
108
150
AZUSA
129
DOWNTOWN LA
WEST LA
84
134
LENNOX
116
LA HABRA
95
ANAHEIM
ONTARIO
112
RIALTO
174
116
SAN BERNARDINO
200
CHINO
140
RIVERSIDE

Figure 2-3. Expected Annual Geometric Mean Hi-Vol Levels for the 1972 Base Year

Expected Maximal 24 Hour Levels for the 1972 Base Year

Figure 2-4 presents the expected maximal 24 hour levels for the 1972 base year at the 15 monitoring sites. These expected measured maxima have been calculated from the statistical distributions for the present APCD monitoring frequency (60 to 90 days per year). The expected actual maxima (assuming monitoring was done every day) would be higher than these values; Table 2-6 illustrates this difference.

In Support Document #1, the values in Figure 2-4 were compared to the historical APCD record of maximal 24 hour levels for the years 1967 to 1973. This served as a check against the possibility that the 7/71 to 6/73 period was meteorologically unusual. The historical record tended to confirm the calculated 24 hour max values, with the exception that the calculated values in Los Angeles County were about 10% lower than typical historical maxima in that county. Possible reasons for this discrepancy are discussed in the Support Document.

Analyses were also made of Hi-Vol seasonal patterns at various locations and of the meteorology associated with maximal Hi-Vol levels. It was found that Hi-Vol levels in the western-coastal area are greatest during the winter, on days associated with high values of primary contaminants such as CO. In the eastern-inland area of the Los Angeles Region, Hi-Vol levels are greatest during the summer-fall photochemical smog season. These findings are qualitatively consistent with known facts about particulate origins, meteorology, and pollution distributions in the Los Angeles region. The Los Angeles aerosol is composed of both primary particulate (directly emitted) and secondary particulate (formed in the atmosphere by chemical-physical processes). The primary and secondary sources are of the same order of magnitude, (see Section 2.3).

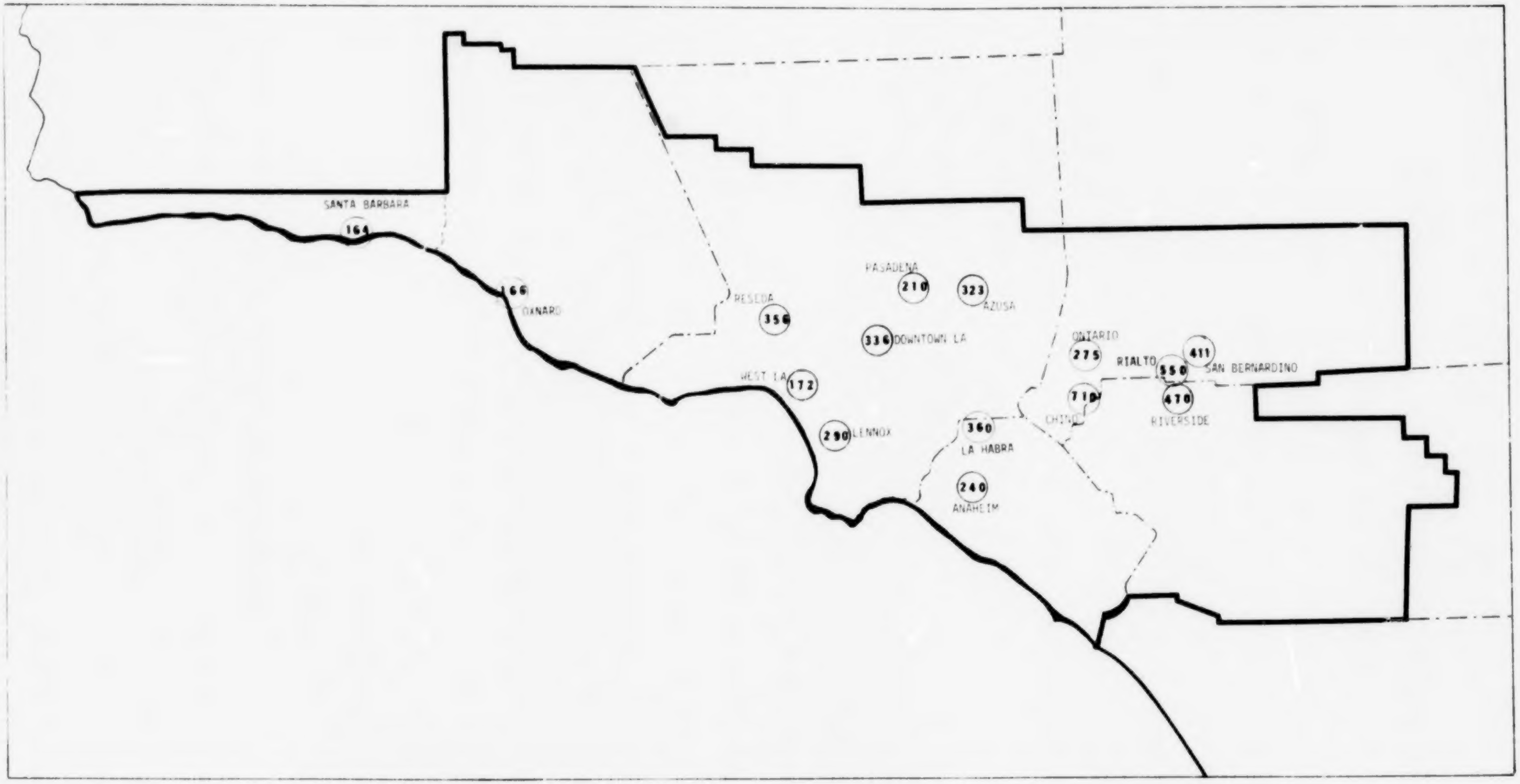

SANTA BARBARA
164
66
OXNARD
RESEDA
356
PASADENA
210
323
AZUSA
336
DOWNTOWN LA
WEST LA
172
290
LENNOX
360
LA HABRA
240
ANAHEIM
ONTARIO
275
710
CHINO
RIALTO
550
411
SAN BERNARDINO
470
RIVERSIDE

Figure 2-4. Expected 24-Hour Max. Hi-Vol Levels for the 1972 Base Year (for the present APCD Monitoring Frequency)

TABLE 2-6 EXPECTED MEASURED 24 HOUR MAXIMA vs. EXPECTED ACTUAL 24 HOUR MAXIMA FOR HI-VOL MONITORING SITES IN THE LOS ANGELES REGION

MONITORING SITE		C_{70} EXPECTED MEASURED 24 HR. MAX. AT PRESENT MONITORING FREQUENCY ($\mu g/m^3$)	C_{365} EXPECTED ACTUAL 24 HR. MAX. ASSUMING DAILY MONITORING ($\mu g/m^3$)
L. A. COUNTY	Lennox	290	340
	Central Los Angeles	336	414
	Reseda	356	446
	West Los Angeles	172	200
	Pasadena	210	247
	Azusa	323	380
ORANGE COUNTY	Anaheim	240	290
	La Habra	360	460
SAN BERN. COUNTY	San Bernardino	411	540
	Ontario	275	360
	Chino	710	1000
	Rialto	550	780
RIVERSIDE COUNTY	Riverside	470	620
VENTURA COUNTY	Oxnard	166	200
SANTA BARB. COUNTY	Santa Barbara	164	200

Now, it is known that primary contaminants (e.g., CO) reach maximal levels in the western-coastal area of the basin and that the highest values occur in the winter. It is also known that photochemical smog, a principle source of secondary contaminants, is most intense in the eastern-inland portions of the basin and that summer-fall is the "in-season" for photochemical pollution. The high winter values for suspended particulates in the western-coastal area during the winter appear to reflect the importance of primary aerosol, (particularly to the western area). The high summer-fall values for particulates in the eastern-inland area seem to reflect the importance of secondary aerosol, (particularly to the eastern area).

Sub-Regions for Control Strategy Formulation

In formulating control policies for an air basin, it is useful to distinguish sub-areas with different maximal characteristic Hi-Vol levels. The object of control policy is to reduce each of these characteristic levels to the air quality standards. In some cases, different degrees of control may be required for different sub-areas. In choosing an explicit number of sub-areas to consider, a balance should be struck between simplicity and realism. The fewer the sub-areas, the easier it is to formulate, implement, and administer a control program. The greater the number of sub-areas, the more specific and efficient is the control program.

For the purpose of control strategy formulation in the Los Angeles Region, a three area classification is proposed (see Figure 2-5). Table 2-7 lists the sub-areas along with the characteristic maximal AGM'S and 24 hour extrema for the 1972 base year. It should be emphasized that the characterstic values in Table 2-7 are not the typical values for

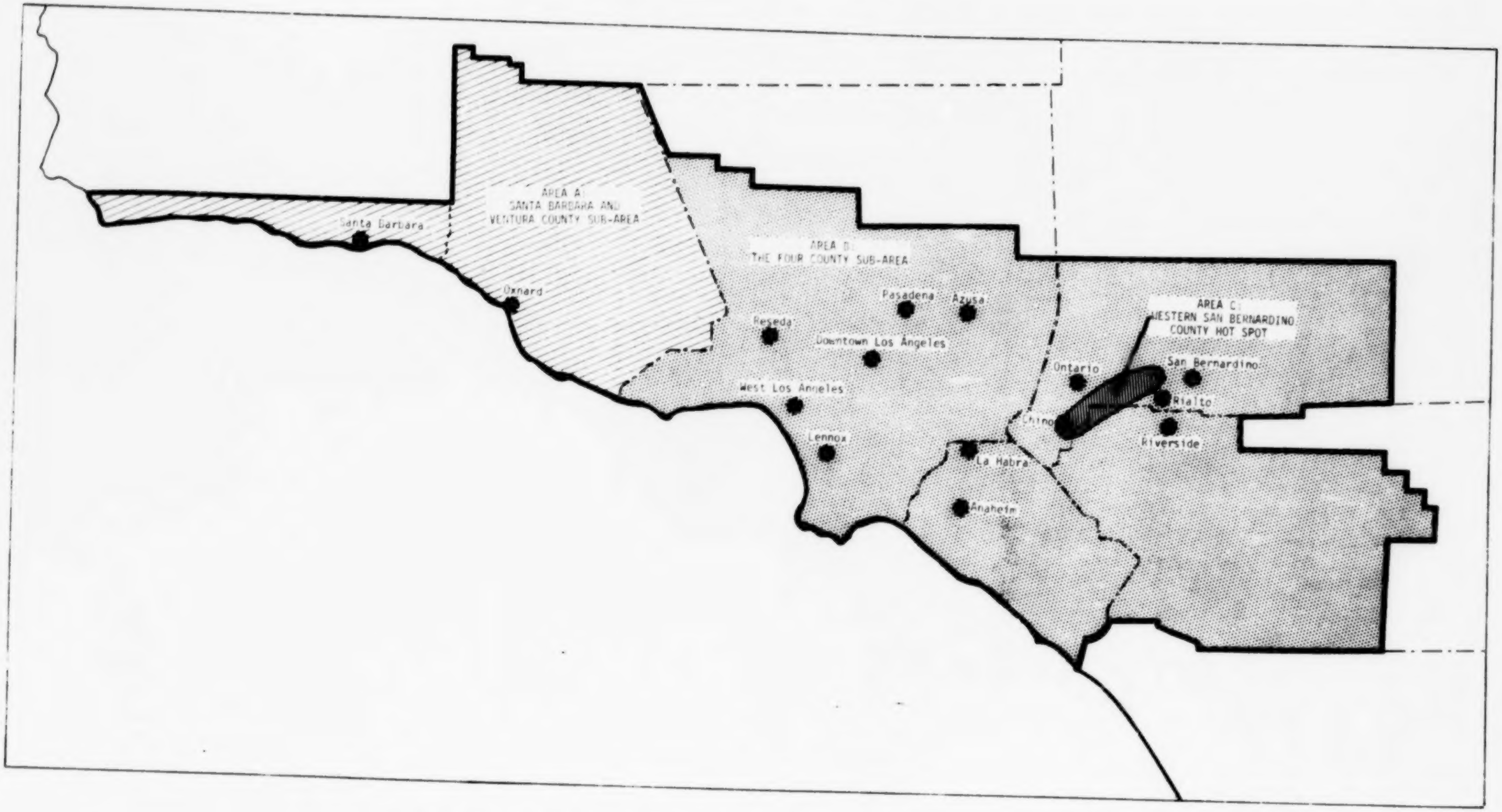

AREA A:
SANTA BARBARA AND
VENTURA COUNTY SUB-AREA
Santa Barbara
Oxnard
AREA B:
THE FOUR COUNTY SUB-AREA
Pasadena
Azusa
Reseda
Downtown Los Angeles
West Los Angeles
Lennox
La Habra
Anaheim
AREA C:
WESTERN SAN BERNARDINO
COUNTY HOT SPOT
Ontario
San Bernardino
Rialto
Chino
Riverside

Figure 2-5 Sub-Areas for Control Strategy Formulation

the region but rather the maximal values among all monitoring sites in the region. These characteristic values are approximate; the numbers have been rounded to reflect their approximate nature.

TABLE 2-7 CHARACTERISTIC MAXIMAL HI-VOL LEVELS IN THREE SUBAREAS OF THE LOS ANGELES REGION -- (FOR BASE YEAR 1972)

AREA	CHARACTERISTIC MAXIMAL AGM	CHARACTERISTIC MAXIMAL 24 HR. EXTREMUM
A. Ventura and Santa Barbara Counties	80 $\mu g/m^3$	180 $\mu g/m^3$
B. Los Angeles, Orange, San Bernardino, and Riverside Counties (except area C below)	150 $\mu g/m^3$	470 $\mu g/m^3$
C. Western San Bernardino County Hot-Spot	200 $\mu g/m^3$	700 $\mu g/m^3$
FEDERAL STANDARDS		
Primary	75 $\mu g/m^3$	260 $\mu g/m^3$
Secondary	60 $\mu g/m^3$	150 $\mu g/m^3$

2.2 EMISSION INVENTORIES AND PROJECTIONS

The development of air pollution control strategies for the improvement of ambient air quality depends on a detailed knowledge of the quantity and character of pollutant emissions in the region. This section summarizes the effort performed in this study to develop an inventory for emissions of particulates, SO_2, NO_x, and reactive hydrocarbons in the Metropolitan Los Angeles Region. Section 2.2.1 describes the development of the 1972 base year emission inventory. Section 2.2.2 outlines the development of a projected emissions inventory for the future years, 1977 and 1980. A more detailed discussion of these aspects of the study (emissions quantification and projection) may be found in Support Document #2, [2].

2.2.1 Development of the 1972 Base Year Inventory

A preliminary search of available emissions data revealed that 1972 would be the most recent year in which reasonably complete emissions information could be obtained. Hence 1972 was selected as the base year for the emissions inventory. Data sources were investigated, study policies and assumptions were formulated, emission estimation methodologies were established, and subsequently, the 1972 base year inventory was compiled. The following sections describe the various elements of the inventory development.

Data Sources and Study Policies

Previous studies, [23],[24],[25], in which air pollutant emission in the Los Angeles region were quantified were obtained for review. The utility of these studies was found to be rather limited in terms of their applicability to the present study. Emission inventories which have been previously compiled are generally incomplete in the sense that they do not reflect more current and extensive data now available and they do not provide a sufficiently detailed characterization of the emission sources. Because of these limitations, TRW developed a separate emission inventory based on consideration of various emission studies involving the many specific emission source categories. The following discussion relates some of the more important studies, data sources, and general rationale utilized to select the data and policy base, which was subsequently used to construct the base year emission inventory.

- Stationary Sources:

  The Los Angeles Air Pollution Control District maintains a staff of emission analysts for each of the major emission source categories and a source permit file containing detailed information for each of the large individual emission sources in the county. No other agency is in as favorable a position to characterize the air pollution arising from stationary sources. The air pollution control districts of Orange, San Bernardino, Ventura, Riverside, and Santa Barbara are similarly in a favorable position to assess the emissions from stationary sources within their jurisdiction. Hence the stationary source inventories developed by the APCD's were considered the most appropriate data sources except for special cases in which it was demonstrated that a more extensive alternative data base was available. The two most significant special cases in which APCD emission data were disregarded in favor of other information concerned: 1) emissions of NO_x from stationary sources in the Los

Angeles Region, (determined in a recent study by KVB Engineering, Inc. while under contract to the Air Resources Board), and 2) emissions of particulates, SO_2, and NO_x from Southern California Edison power plants, (available from emissions study performed by the Southern California Edison Company).

Additional data was obtained from the National Emissions Data System for individual sources generating greater than 100 tons/year of pollutants. These data were used specifically to characterize spatial emission distributions (discussed later in this section).

- Motor Vehicle Emissions:

  Several sources of information were investigated during the preparation of the motor vehicle emission source inventory. Calculations of SO_2, NO_x, and reactive hydrocarbon emissions were performed by utilizing published EPA emission factors [26] in preference to methodology developed by the Los Angeles APCD. Because of the relatively limited attention addressed to the quantification of emissions of particulates from motor vehicle exhaust in previous studies, several recent automotive emission studies were synthesized to develop particulate emission factors which were believed to be more representative of motor vehicle emissions than either the EPA or APCD published emission factors.

- Aircraft Emissions:

  Both the EPA and the Los Angeles APCD have published separate emission inventories for aircraft operations at the Los Angeles International Airport. The APCD figures are based on a recent detailed study, [27], in which emission factors were derived from field measurements. These were considered the most acceptable information source for the present study. Aircraft emissions at other airports were determined from the estimates contained in the various APCD emission inventories.

- Hydrocarbon Reactivity Factors:

  Hydrocarbon emissions were tabulated in terms of reactive hydrocarbons, determined by employing reactivity factors established from an EPA analysis of empirical smog chamber data, [25]. These reactivity coefficients express the potential of the organic emissions to form photochemical oxidant, and do not specifically represent the aerosol-forming potential of organics. However, it has been found that organics which are non-reactive in terms of oxidant yield are generally also non-contributory to aerosol formation. Hence, while the EPA reactivity scale expresses potential for oxidant formation, it also provides a limited representation of the aerosol-forming potential, and as such, is more suitable for use in this study than a total hydrocarbon scale.

- Suspended and Total Particulates:

  In the primary particulate emission inventory developed in this study, a distinction was incorporated between suspended particulates and total particulates. Suspended particulates were assumed to be those actually measured at sampling stations, whereas the term total particulates refered to all source emissions of particulate matter, including the larger particles which settle out on surfaces neighboring the emissions source. In the emission inventory 10 microns was chosen as the dividing point between suspended and total particulates. The size distinction and delineation of the two separate segments of the particulate inventory were considered important in the study since ambient air quality is related to the suspended portion of the particulate inventory, while air pollution control technology for particulate matter is more commonly expressed in relation to total particulate emissions.

- The Four County Area:

  Air monitoring and meteorological data have demonstrated that the air resources of Santa Barbara and Ventura counties are relatively remote from the remaining "Four County Area" of the South Coast Air Basin in a meteorological sense, and that consequently the air pollution problems of these two portions of the basin are separate. In addition, air monitoring data demonstrate that the National Ambient Air Quality Standards for particulate concentrations are seldom exceeded in Santa Barbara and Ventura. These factors would suggest the sensibility of developing separate air resources management techniques for the Four County Area and the northern portion of the air basin, directing the major effort of the study to develop an air program plan for the worst case of the basin, the Four County Area.

The 1972 Baseyear Inventory

Table 2-8 provides the 1972 Four County Area emissions inventory developed in this study. Stationary sources generate the majority of primary particulate and SO_2 emissions, while mobile sources account for a high percentage of the NO_x and reactive hydrocarbon emissions. The relative role of each of the various source categories in overall emissions totals is shown in Figure 2-6. Stationary fuel combustion and motor vehicles are the two greatest pollutant emitters, accounting for the majority of all pollutants emitted in the Four County Area. In 1972, stationary fuel combustion was the largest single source of SO_2 emissions, while motor vehicles were the greatest emitters of primary particulates, NO_x, and reactive hydrocarbons. The other most significant emission sources are petroleum operations, chemical processing, and aircraft activity. The methodology employed in deriving emission estimates for the individual source categories is described in the following discussion.

- Stationary Emission Sources:

  Inventories provided by each of the local air pollution control districts were used in the compilation of the

TABLE 2-8. 1972 EMISSION INVENTORY OF PRIMARY PARTICULATES AND GASEOUS PRECURSORS FOR THE FOUR COUNTY AREA

Source Category	Emissions, tons/day				
	Primary Particulates		SO_2	NO_x	Reactive Hydrocarbons
	Total	Suspended			
Stationary Sources					
Petroleum					
Petroleum Refining	3.0	3.0	60	67.5	7.0
Petroleum Marketing	---	---	---	---	67.1
Organic Solvent Operations					
Industrial Spray Booths	8.0	7.2	---	---	---
Surface Coating	---	---	---	---	10.0
Dry Cleaning	---	---	---	---	1.0
Degreasing	---	---	---	---	10.0
Other	---	---	---	---	22.0
Chemical Processing					
Chemical Manufacturing	10.2	9.2	---	---	---
Sulfur Recovery	---	---	95	---	---
Other	---	---	2.0	0.4	---
Metallurgical Operations					
Sand Handling	0.7	0.7	---	---	---
Melting and Pouring	11.6	11.6	13.0	0.5	---
Mineral Processing					
Aggregate Operations	2.8	2.5	---	---	---
Abrasive Blasting	2.5	2.2	---	---	---
Other	6.0	5.5	1.4	---	---
Incineration Operations	2.2	2.0	---	1.6	.3
Fuel Combustion					
Power Plants	22.3	22.1	180	93.5	---
Industrial	12.0	12.0	27.6	115	---
Domestic	10.6	10.6	.3	74.1	---
Agricultural					
Orchard Heaters	2.2	2.2	1.1	---	.4
Stationary Source Subtotal	93	90	381	353	118
Mobile Sources					
Motor Vehicles					
Light Duty	58.6	47.5	39.8	747	827
Heavy Duty	1.7	1.4	.6	27	31
Diesels	4.1	3.3	8.5	117	12
Motorcycles and Miscellaneous	5.8	4.7	---	59	91
Motor Vehicle Tire Wear	31.1	15.2	---	---	---
Aircraft					
Jet	11.5	11.4	3.4	12.4	9.9
Piston	3.5	2.8	.2	6.2	5.8
Ship and Railroads	1.5	1.2	10.8	24.0	---
Mobile Source Subtotal	118	88	63	993	977
Total Inventory	212	178	444	1345	1095

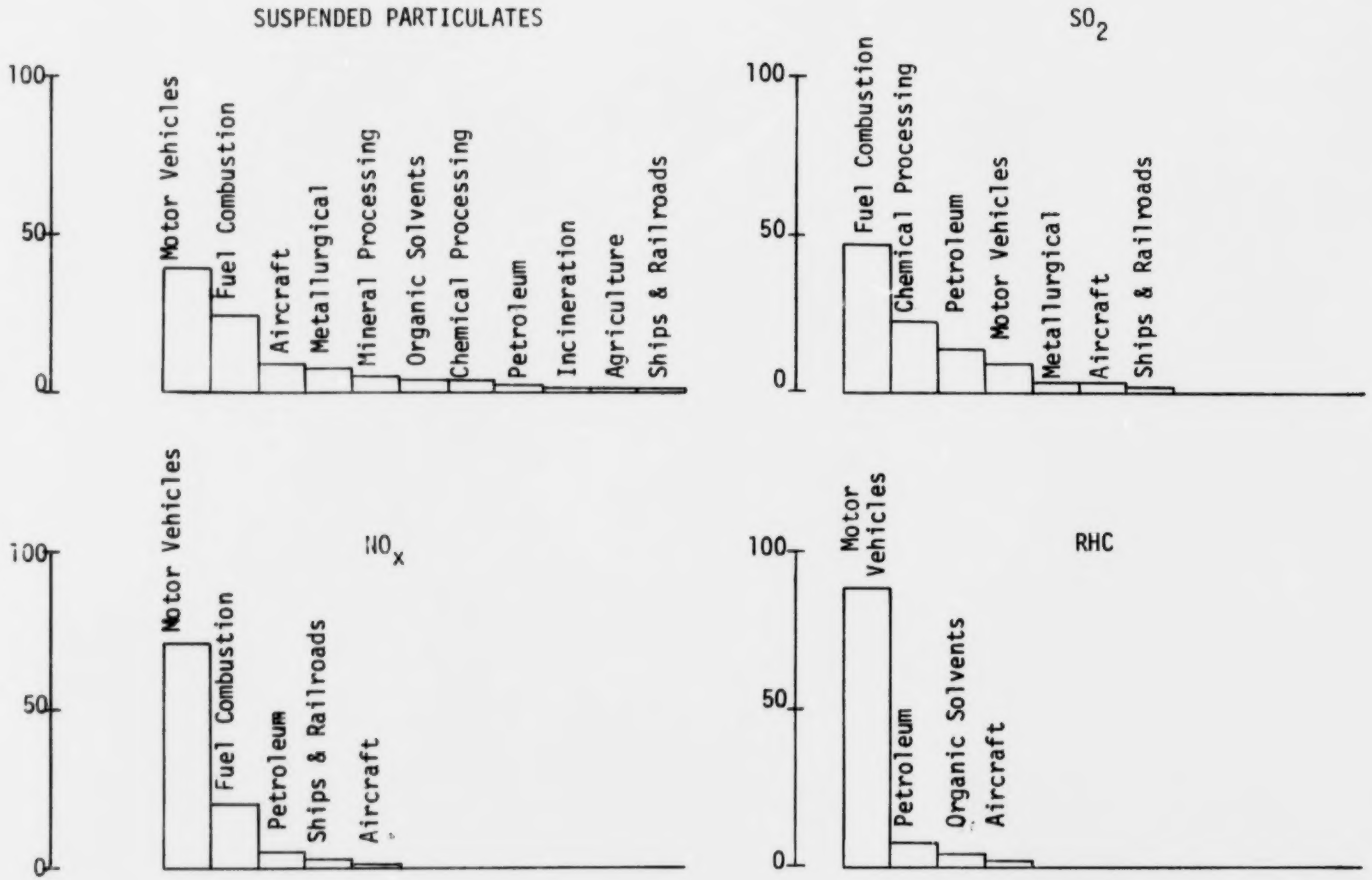


Figure 2-6. The Role of the Various Source Categories in Emission of Particulates and Gaseous Precursors in the Four County Area, 1972.

stationary source emission inventory of this study. Exceptions to this procedure were incorporated for estimation of power plant emissions and emissions of NO_x from all source categories. Power plant emission estimates were obtained from Southern California Edison for their power plants. These emission estimates were scaled upward to include Los Angeles Department of Water and Power plants by applying the assumption that emissions are proportional to electric generating capacity. Estimates of NO_x emissions from the various source categories were obtained from the inventory provided by KVB Engineering.

The reactive hydrocarbon emission inventory was adjusted to reflect the current set of reactivity coefficients derived by the EPA. The total particulate emission inventory was adjusted to a suspended particulate inventory by application of suspension factors relating to the various source categories. The suspension factors were determined primarily by consultation with Los Angeles APCD air pollution emission analysts (see Support Document #2), and are related directly to the degree of particulate pollution control presently applied to a given particulate emission source.

- Mobile Source Emissions:

Emission estimates of particulates from light duty motor vehicle exhaust were based on empirical results of automotive studies by Habibi and Ter Haar, [28]. A synthesis of findings from these studies yielded a set of particulate emission factors for new cars and old cars, and for both suspended particulates and total particulates. These emission factors were utilized in conjunction with the regional vehicle age distribution to derive a weighted average emission factor for exhaust particulates. Particulate emissions (suspended and total) for the Four County Area were then computed from vehicle mileage data extracted from the Los Angeles Regional Transportation Study, [24]. Emissions of gaseous percursors from light and heavy duty gasoline powered motor vehicles were calculated using current EPA emission factors and deterioration factors, combined with vehicle population data from R. L. Polk and Company, and VMT data from the Los Angeles Transportation Study. The details of the procedure for these calculations are described in Appendix C of Support Document #2,[2]. The EPA emission factors were selected for the emission calculations by direction of the project officer for the study. It was recognized however, that a controversy presently exists between the EPA and the California Air Resources Board concerning emission factors of gasoline powered motor vehicles. These differences result in two distinct motor vehicle emission inventories and lead to substantial differences in estimates of potential emission reductions via motor vehicle controls.

Motor vehicle SO_2 exhaust emissions were estimated using EPA emission factors, adjusted to reflect the regional content of sulfur (.067%) in gasoline sold in Southern California.

Emissions from heavy-duty diesel vehicles were estimated using EPA emission factors (expressed in pounds of pollutant per gallon of fuel) and 1970 diesel fuel consumption data obtained from the National Emissions Data System. Fuel consumption for 1970 was projected to 1972 by adjusting by the diesel truck registration growth rate.

Particulate and gaseous precursor emissions from motorcycles were calculated using EPA emission factors, population data from the California Department of Motor Vehicles, and an assumed annual VMT of 4000 miles per cycle, [29].

The quantity of aircraft, ship and railroad particulate and gaseous precursor emissions were obtained from the supplement to the Implementation Plan - South Coast Air Basin, submitted to the Air Resource Board by the local APCD's.

Particulates are also emitted to the atmosphere in substantial amounts due to vehicle tire wear. Calculations for these emissions were based on EPA emission factors. The suspended portion of matter arising from tire wear is estimated to be 49% of the total particulate emissions, [30].

> The reactive hydrocarbon emission inventory for mobile sources was adjusted to reflect the current set of reactivity coefficients derived by the EPA, and the total particulate emission inventory was adjusted to a suspended matter inventory by application of suspension factors determined for emissions of each of the individual source categories.

Locational Considerations

A special feature of this study was the presentation of the spatial distribution of emissions on maps. Typically, emission inventories are expressed on an aggregated basin-wide basis with no indication of spatial distribution. The emission maps were produced to provide an aide in evaluating locational aspects of control strategies.

Figures 2-7 through 2-10 provide the approximate spatial distribution of emissions of particulates, reactive hydrocarbons, sulfur dioxide, and nitrogen oxides in the Los Angeles Region for the 1972 base year. These maps were formulated by locating the most significant emission sources, and then assuming a simple proportional relationship between the known source activity level (such as the megawatt capacity of a power plant, or the barrels/day throughput of a refinery) and the aggregated overall emission totals of the emission inventory of Table 2-7. The procedure is explained in more detail in Support Document #2, [2].

Examination of the emission density maps reveals that emission of reactive hydrocarbons and nitrogen oxides are distributed evenly throughout the basin, in a pattern which parallels the distribution of vehicular activity (the primary source of these pollutants). The density

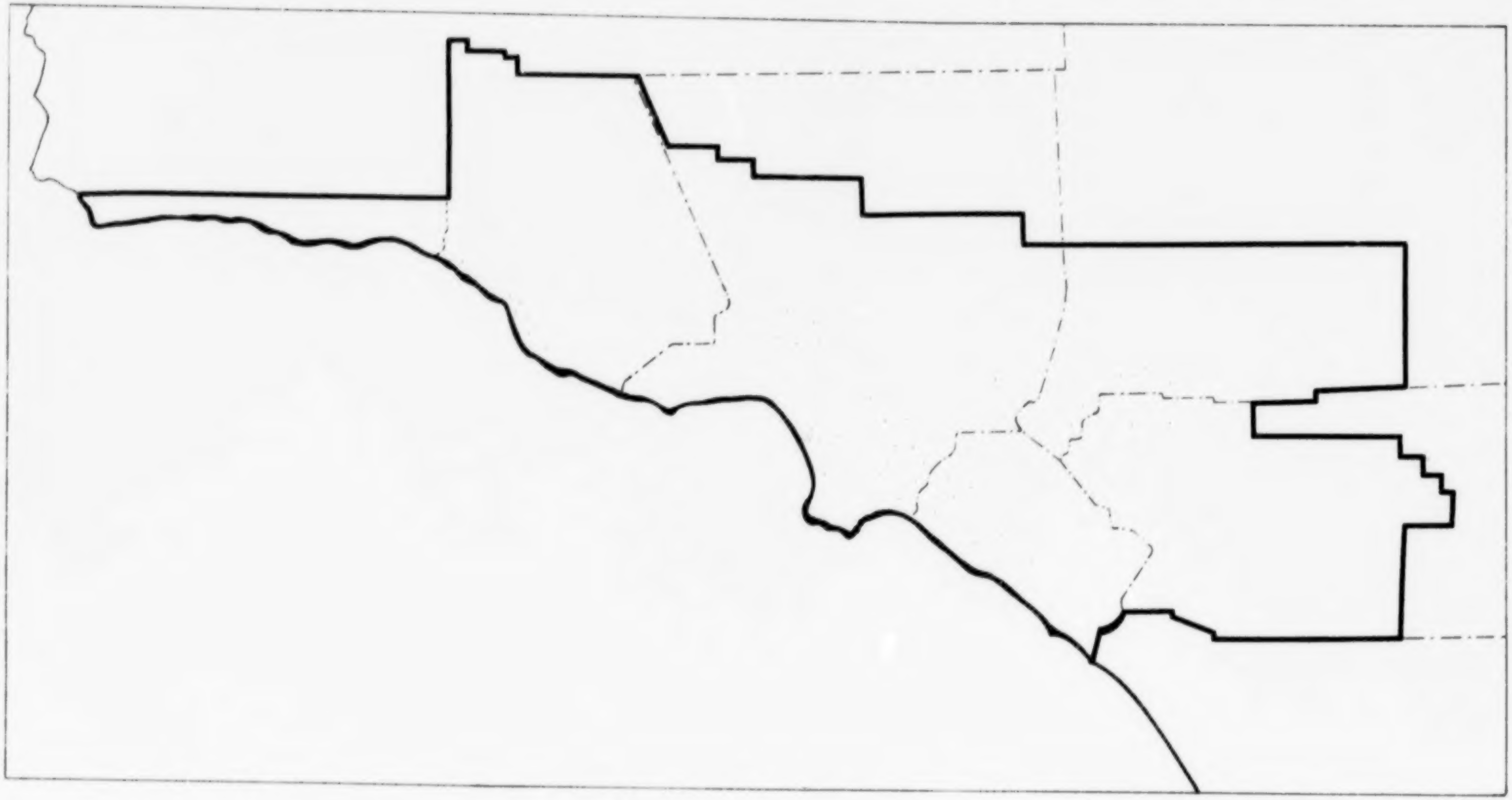


Figure 2-7. Particulate Emission Density Map.
1 Dot = 2 Tons/Day Total Particulate Emissions

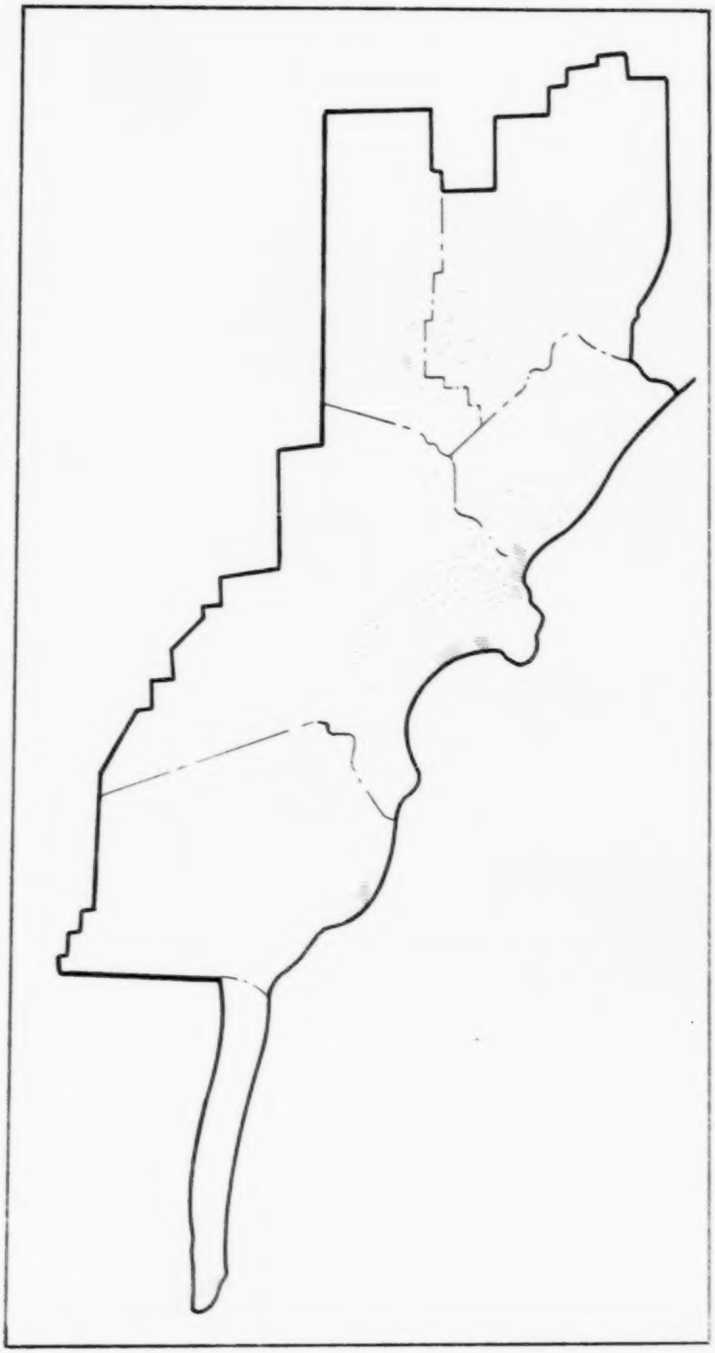


Figure 2-8. Sulfur Oxides Emissions Density Map.
1 Dot = 2 Tons/Day SO_x Emissions

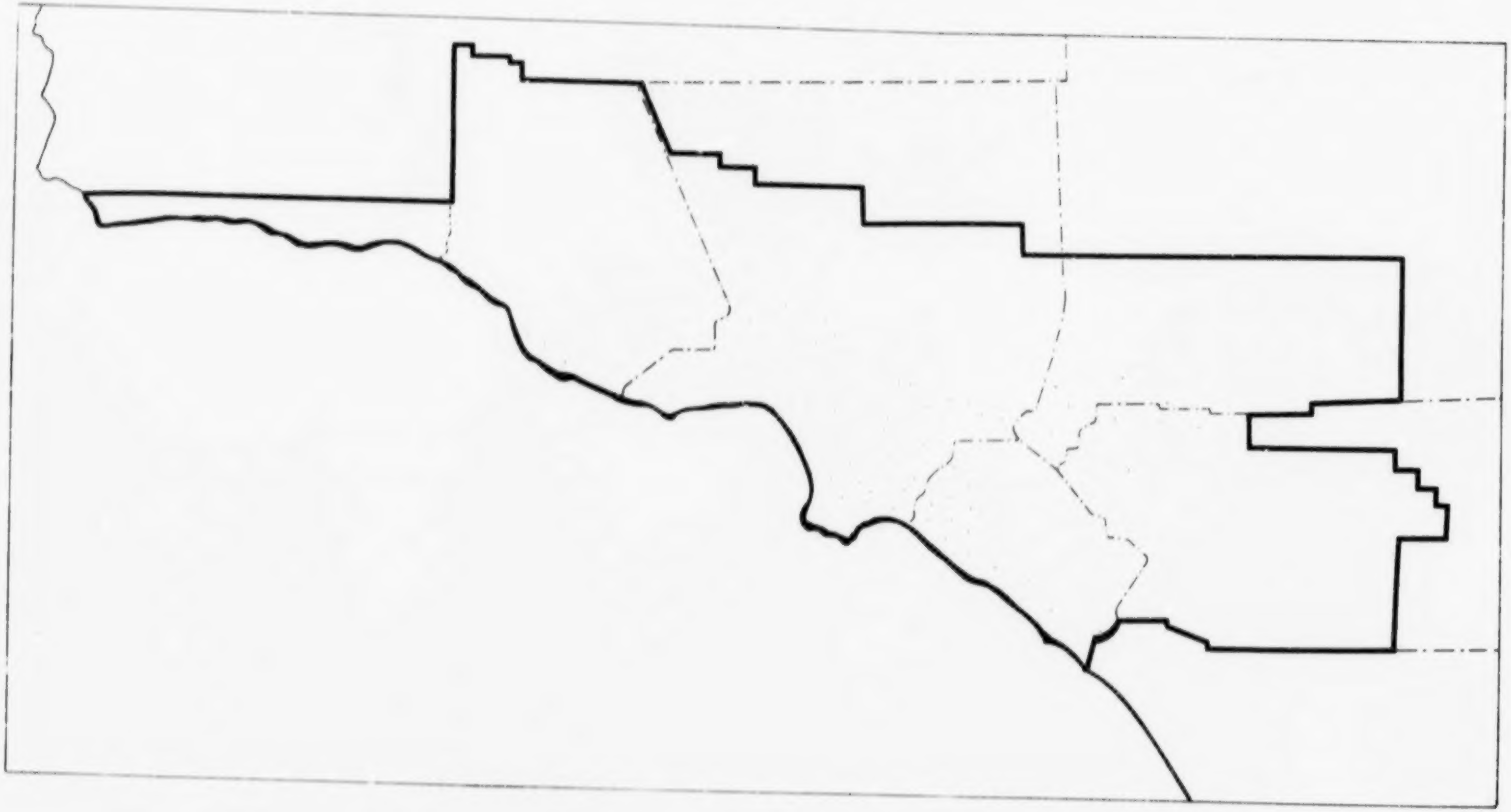


Figure 2-9. Reactive Hydrocarbon Emission Density Map.
1 Dot = 10 Tons/Day of Reactive Hydrocarbon Emissions

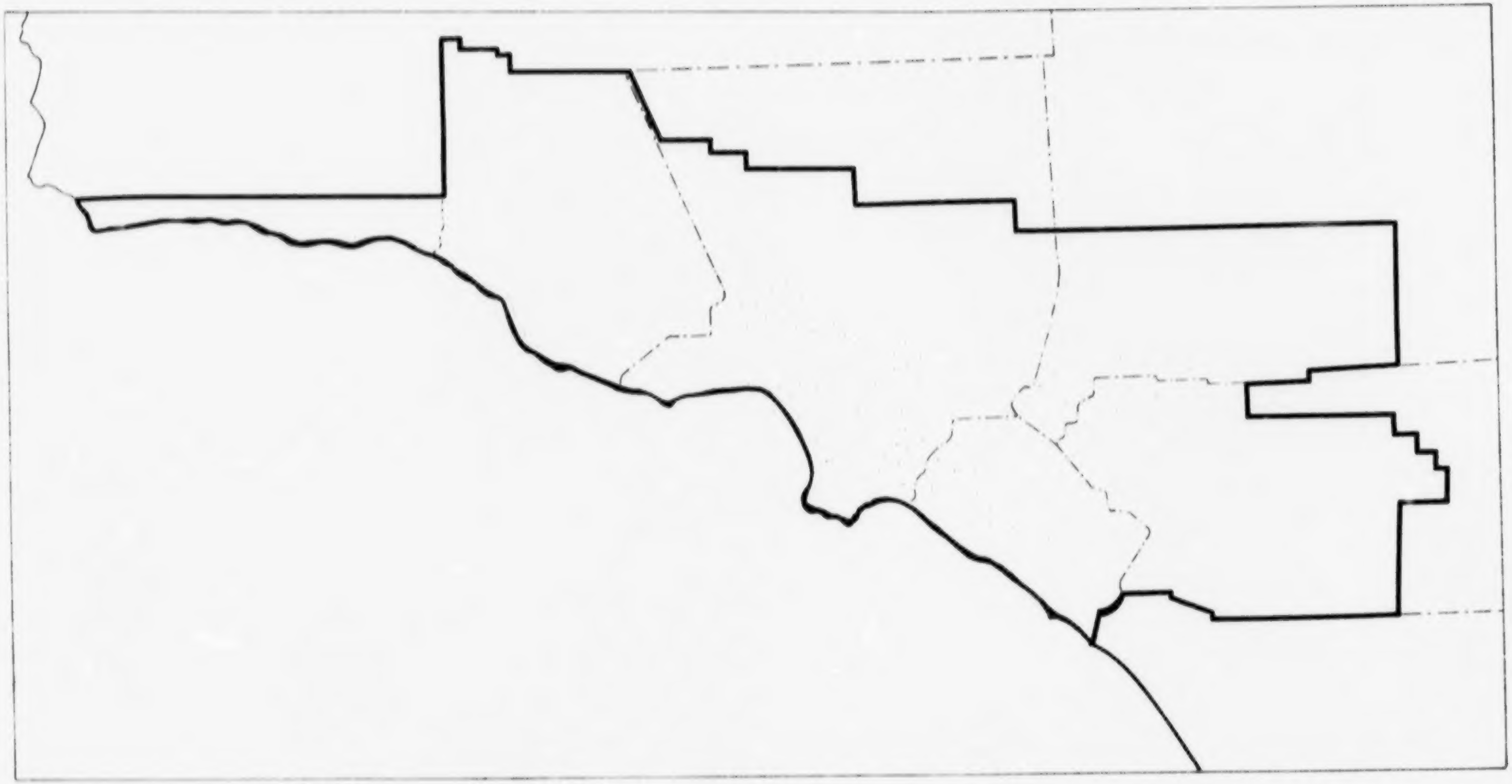


Figure 2-10. Nitrogen Oxides Emission Density Map.
1 Dot = 11 Tons/Day NO_x Emissions

plot of primary particulate matter provides a similar distribution, except for a distinct concentration of particulate emissions appearing in the area of the Los Angeles International Airport. The plot of SO_2 emissions shows intense emission densities in the coastal regions, where power utilities and oil refineries emit the bulk of SO_2 emissions for the Four County Area.

2.2.2 Development of Emission Projections for 1977 and 1980

Predictions of the quantities of particulate and gaseous precursor emissions which will be generated in the Los Angeles Region in 1977 and 1980 were formulated for two sets of future conditions. Projections were made in the first case under the condition that local APCD and federal new car air pollution control programs are implemented. Emission forecasts were formulated in the second case under the condition that the EPA-promulgated air program plan for achieving the oxidant standard is implemented. The following sections describe the development of these emission projections.

Data Sources and Study Policies

A search of the public domain indicated that limited research has been directed toward the development of emission forecasts for the Los Angeles Basin. It was necessary therefore to develop predictions specifically for this study based on various information sources characterizing the anticipated future activities of each of the source categories. The more important data sources, and the general rationale used to select the data and policy base for constructing the projected emission inventories, are related below.

- Stationary Sources:

  The various independent data sources consulted with respect to the various different stationary source categories and the basic assumptions regarding the projection of the stationary emission inventory are summarized in Table 2-9. For the majority of source categories, the projected rate of increase of air pollution emissions was considered to be equal to the rate of increase in total employment in the county. Employment trends and predictions were available from a study performed by the Wells Fargo Bank, [31]. Projected emissions from fuel combustion were predictable from projections of natural gas supplies available from the Southern California Gas Company. It was determined that emissions from refining activity of the petroleum industry could be projected based on environmental impact studies assessing the nature of changing emissions at oil refineries expecting to develop new facilities by 1980. Future emissions of reactive hydrocarbons resulting from petroleum marketing activities were assumed to be reflected by historical gasoline marketing trends, (4% per year growth rate), available from a previous study of the Metropolitan Los Angeles Region by TRW, [24].

- Motor Vehicle Emissions:

  Emissions from motor vehicles have been previously projected for the purpose of oxidant control strategy development, [24].

TABLE 2-9. SUMMARY OF ASSUMPTIONS AND DATA SOURCES USED FOR BASELINE EMISSION INVENTORY PROJECTIONS TO 1977 AND 1980

	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura
Petroleum						
(1) Production	1	1	2	2	2	1
(2) Refining	9	2	2	2	2	2
(3) Marketing	3	3	3	3	2	3
Organic Solvent						
(1) Surface Coating	4	2	4	4	4	4
(2) Dry Cleaning	4	2	4	4	4	4
(3) Degreasing	4	4	4	4	4	4
(4) Other	4	4	4	4	4	4
Chemical						
(1) Petrochemical	4	2	4	2	2	4
(2) Sulfur Plants	4	2	4	2	2	4
(3) Sulfuric Acid Plants	4	2	4	2	2	4
(4) Pulp and Paper	4	2	4	2	2	4
(5) Other	4	4	4	2	2	4
Metallurgical						
(1) Ferrous	4	4	4	4	2	2
(2) Non Ferrous	4	4	4	4	2	2
Mineral						
(1) Glass and Frit	4	4	4	4	4	4
(2) Asphalt Batching	4	4	4	4	4	4
(3) Asphalt Roofing	4	4	4	4	4	4
(4) Cement Production	4	4	4	4	4	4
(5) Concrete Patching	4	4	4	4	4	4
(6) Other	4	4	4	4	4	4

TABLE 2-9. SUMMARY OF ASSUMPTIONS AND DATA SOURCES USED FOR BASELINE EMISSIONS INVENTORY PROJECTIONS TO 1977 AND 1980 (CONTD)

	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura
Incineration						
(1) Open Burning (Dumps)	2	2	2	2	2	2
(2) Open Burning (Backyard)	2	2	2	2	2	2
(3) Incinerators	8	8	8	2	2	2
(4) Other	2	2	2	5	2	5
Combustion of Fuel						
(1) Steam and Power Plants	6	6	6	6	6	6
(2) Other Industrial	7	7	7	7	7	7
(3) Domestic and Commercial	7	7	7	7	7	7
Agricultural						
(1) Debris Burning	2	5	5	2	5	5
(2) Orchard Heaters	2	2	5	5	2	5
(3) Agricultural Production Processing Plants	2	2	5	2	2	5

Assumption #1: There will be no change of emission levels from 1972 because no new oil fields or increased production from existing fields and refineries is expected.

Assumption #2: There were no emissions from these sources in 1972 and none is expected in the future.

Assumption #3: The historical 4% per year growth rate in gasoline sales is expected to hold true in the future. No attempts have been made to assess the impact of possible fuel shortages on gasoline sales.

TABLE 2-9. SUMMARY OF ASSUMPTIONS AND DATA SOURCES USED FOR BASELINE EMISSIONS INVENTORY PROJECTIONS TO 1977 AND 1980 (CONTD)

Assumption #4: The rate of increase in emissions is equal to the rate of increase in the total employment of each county, which is given below:

Los Angeles	1.5% per year
Orange	3.5% per year
Riverside	2.5% per year
San Bernardino	2.3% per year
Santa Barbara	2.3% per year
Ventura	2.9% per year

Source: "Moving Ahead - Wells Fargo Looks at California," Wells Fargo Bank, 1973.

Assumption #5: The emissions from these sources are assumed to remain constant through 1980.

Assumption #6: Emission projections were assumed to be best represented by Southern California Edison.

Assumption #7: Emission projections were assumed to be reflected best by the 19/3 California Gas Report.

Assumption #8: Emissions are assumed to increase at the same rate as population in each county.

Assumption #9: Emission projections reflecting the anticipated expansions at local refineries (Atlantic Richfield and Standard Oil) were based on emission estimates from environmental impact statements associated with the proposed Standard Oil expansion project (as conveyed to TRW by the EPA, [33]).

However, these projections were made prior to the granting of delay to the automobile manufacturers in meeting the Clean Air Act standards. Moreover, these projections did not address primary particulates and the gaseous percursor, SO_2. Hence, new projections were developed for the entire range of motor vehicle types to incorporate the modified status of vehicle emission control regulations and to characterize the specific pollutants of interest in this study. The results of recent automotive studies were synthesized in the approach to develop particulate emission factors representative of future motor vehicles.

Projection of emissions from uncontrolled motor vehicles (such as exempted automobiles, motorcycles, dune buggies, farm equipment, and earth moving equipment) has been studied by Automotive Environmental Systems in a contract effort for the Air Resources Board, [28]. The study includes predictions of emissions from uncontrolled motor vehicle sources from 1970 to 1980 for each air quality region in California.

- Aircraft Emissions

In accord with the data sources selected for the base year aircraft emission inventory, projected aircraft emissions for the various counties were determined based on predicted jet emission trends identified by the

Los Angeles APCD for the Los Angeles International Airport. Piston aircraft emissions were projected to the future based on an aviation study performed by the System Development Corporation, [32].

Projected Emissions Inventory for 1977 and 1980

Table 2-10 provides the baseline emissions inventory summary for 1972, 1977, and 1980, when present emission control programs (APCD control plans in combination with the federal new car emission controls) are implemented. Adding additional emission controls by implementing the EPA-promulgated air program (which includes vapor recovery systems at gasoline stations, additional controls on organic solvent usage, a motor vehicle inspection/maintenance program, and catalytic converter retrofit to light duty motor vehicles) results in the projected emission inventory shown in Table 2-11. The overall emissions totals in future years for the two different control programs are illustrated in Figures 2-11 to 2-14. For either control program, emissions of primary particulates, SO_2, and NO_x are projected to increase substantially by the years 1977 and 1980. These increased emissions are due primarily to two factors: growth of the category sources and increasing utilization of fuel oil (replacing the cleaner-burning natural gas) in stationary combustion equipment. Due to intensive efforts to meet the oxidant ambient air standards, reactive hydrocarbon emissions in the Four County Area will be reduced by more than one-half by the year 1980. Figures 2-11 to 2-14 show that the control measures of the EPA air program are most effective in reducing hydrocarbon emissions below the levels expected under presently scheduled control programs. The EPA program would reduce reactive organic emissions an additional 15% beyond the emission

TABLE 2-10. PROJECTED EMISSION INVENTORY FOR THE FOUR COUNTY AREA WHEN THE PRESENT EMISSIONS CONTROL PROGRAM IS IMPLEMENTED

Process Category	Suspended Particulates			SO_2			NO_x			RHC		
	1972	1977	1980	1972	1977	1980	1972	1977	1980	1972	1977	1980
Stationary Sources												
Petroleum	3.0	3.0	3.0	60.0	60.0	60.0	67.5	67.5	67.5	67.1	71.1	71.1
Organic Solvent	7.2	7.7	7.8	---	---	---	---	---	---	43.0	45.9	45.9
Chemical	10.2	10.7	11.1	97.0	10.0	10.0	0.4	0.5	0.5	---	---	---
Metallurgical	12.3	13.4	14.0	13.0	15.0	15.9	0.5	0.6	0.6	---	---	---
Mineral	10.3	11.0	11.5	1.4	1.7	1.8	---	---	---	---	---	---
Incineration	2.0	2.3	2.3	---	---	---	1.6	1.8	1.8	0.3	0.4	0.4
Fuel Combustion	44.7	82.6	80.7	208.0	374.0	380.0	283.0	672.0	629.0	---	---	---
Agricultural	2.2	2.9	2.9	1.1	1.1	1.1	---	0.3	0.3	0.4	0.4	0.4
Mobile Sources												
Light Duty Vehicles	47.5	45.3	40.2	39.8	41.2	39.9	747	586.0	427	827	460	276
Heavy Duty Vehicles	1.4	1.6	1.7	.6	.8	0.9	27.0	24.7	19.3	31.0	24.1	17.8
Diesels	3.3	3.9	4.1	8.5	9.7	10.4	117	133.7	143.2	12.0	13.7	14.7
Aircraft	14.2	25.7	37.0	3.6	6.5	9.6	18.6	32.2	45.4	15.7	26.7	37.1
Motorcycles, off-road vehicles	4.7	5.6	6.2	---	---	---	59.0	70.2	75.5	91.0	99.2	104
Motor Vehicle tire wear	15.2	17.4	18.6	---	---	---	---	---	---	---	---	---
Ships and Railroads	1.2	1.2	1.2	10.8	10.8	10.8	24.0	24.0	24.0	---	---	---
Total Inventory	178	233	240	444	530	540	1345	1614	1434	1095	741	567

TABLE 2-11. PROJECTED EMISSION INVENTORY FOR THE FOUR COUNTY AREA WHEN THE EPA AIR PROGRAM IS IMPLEMENTED

Process Category	Suspended Particulates			SO_2			NO_x			RHC		
	1972	1977	1980	1972	1977	1980	1972	1977	1980	1972	1977	1980
Stationary Sources												
Petroleum	3.0	3.0	3.0	60.0	60.0	60.0	67.5	67.5	67.5	67.1	17.3	18.2
Organic Solvent	7.2	7.7	7.8	---	---	000	---	---	---	43.0	30.4	30.0
Chemical	10.2	10.7	11.1	97.0	10.0	10.0	0.4	.5	0.5	---	---	---
Metallurgical	12.3	13.4	14.0	13.0	15.0	15.9	0.5	.6	0.6	---	---	---
Mineral	10.2	11.0	11.5	1.4	1.7	1.8	---	---	---	---	---	---
Incineration	2.0	2.3	2.3	---	---	---	1.6	1.8	1.8	0.3	0.4	0.4
Fuel Combustion	44.7	82.6	80.7	208	374	380	283	672	629	---	---	---
Agriculture	2.2	2.9	2.9	1.1	1.1	1.1	---	0.3	0.3	0.4	0.4	0.4
Mobile Sources												
Light Duty Vehicle	47.5	35.1	33.6	39.8	35.6	35.7	747	586	427	827	335	188
Heavy Duty Vehicles	1.4	1.6	1.7	.6	.8	.9	27.0	24.7	19.3	31.0	24.1	17.8
Diesels	3.3	3.9	4.1	8.5	9.7	10.4	117	134	143	12.0	13.7	14.7
Aircraft	14.2	25.7	37.0	3.6	6.5	9.6	18.6	32.2	45.4	15.7	26.7	37.1
Motorcycles, off-road vehicles	4.7	5.6	6.2	---	---	---	59.0	70.2	75.5	91.0	99.2	104
Motor Vehicle tire wear	15.2	17.4	18.6	---	---	---	---	---	---	---	---	---
Ships and Railroads	1.2	1.2	1.2	10.8	10.8	10.8	24.0	24.0	24.0	---	---	---
Total Inventory	178	223	233	444	524	535	1345	1614	1434	1095	547	410

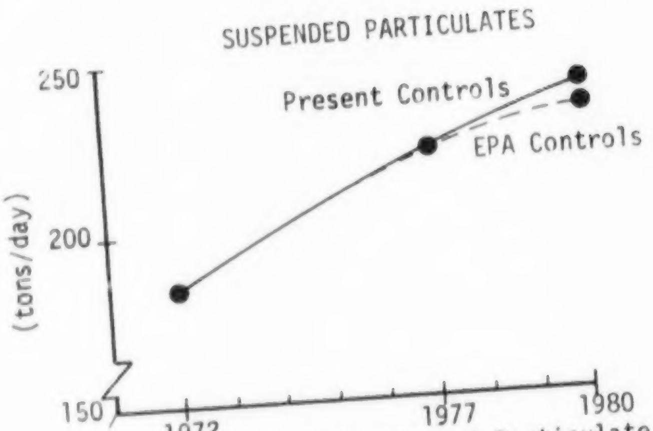


Figure 2-11. Projection of Particulate Emissions in Four County Area

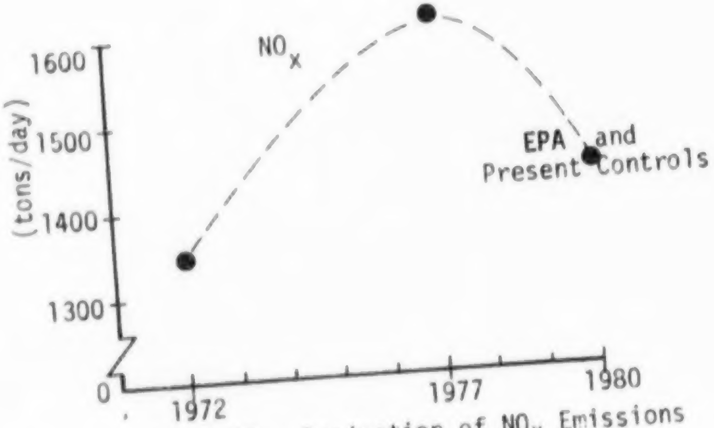


Figure 2-12. Projection of NO$_x$ Emissions in Four County Area

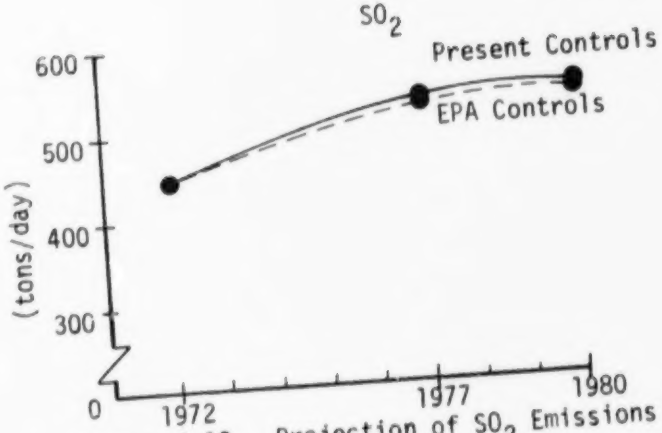


Figure 2-13. Projection of SO$_2$ Emissions in Four County Area

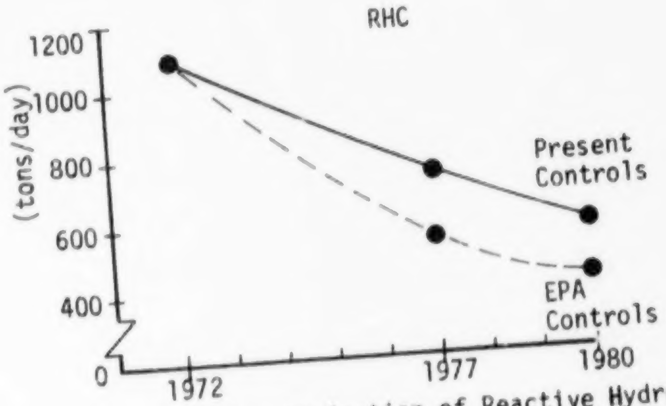


Figure 2-14. Projection of Reactive Hydrocarbon Emissions in Four County Area

control attainable by the existing scheduled air programs. However, as the EPA plan does not address control of particulates, SO_2, and NO_x directly, it provides very minimal additional control of these type of pollutants. In fact, the apparent slight benefit indicated for particulate control in Figure 2-11 from implementation of the EPA plan actually involves a serious trade-off pollution problem. This problem concerns the changing character of motor vehicle particulate pollution (increased generation of sulfates) when catalytic converter controls are utilized in automotive exhaust systems as required by the EPA plan.

Figure 2-15 illustrates the dominant role of four source categories (fuel combustion, petroleum, motor vehicles, and aircraft) in the overall projected emissions inventory of the Four County Area when the EPA air program is implemented. By 1980, the four categories are expected to account for 79% of all the particulate emissions in the Four County Area, 93% of the SO_2, 98% of the NO_x, and 92% of the reactive hydrocarbons. Stationary fuel combustion is expected to become the largest source of particulates, SO_2, and NO_x by 1980, due to increasing fuel oil utilization schedules for combustion equipment in future years, coupled with the effect of increasing controls programmed to reduce motor vehicle emissions substantially by 1980. Motor vehicles will continue to be the most significant source of reactive hydrocarbon emissions, accounting for approximately 88% of the overall inventory. Without significant controls expected until 1979, aircraft emissions are expected to increase markedly over the next decade, and although the overall quantity of pollution arising from aircraft activity is a small portion of the total emissions inventory, it is emitted in a limited area and therefore constitutes a significant local source of pollution.

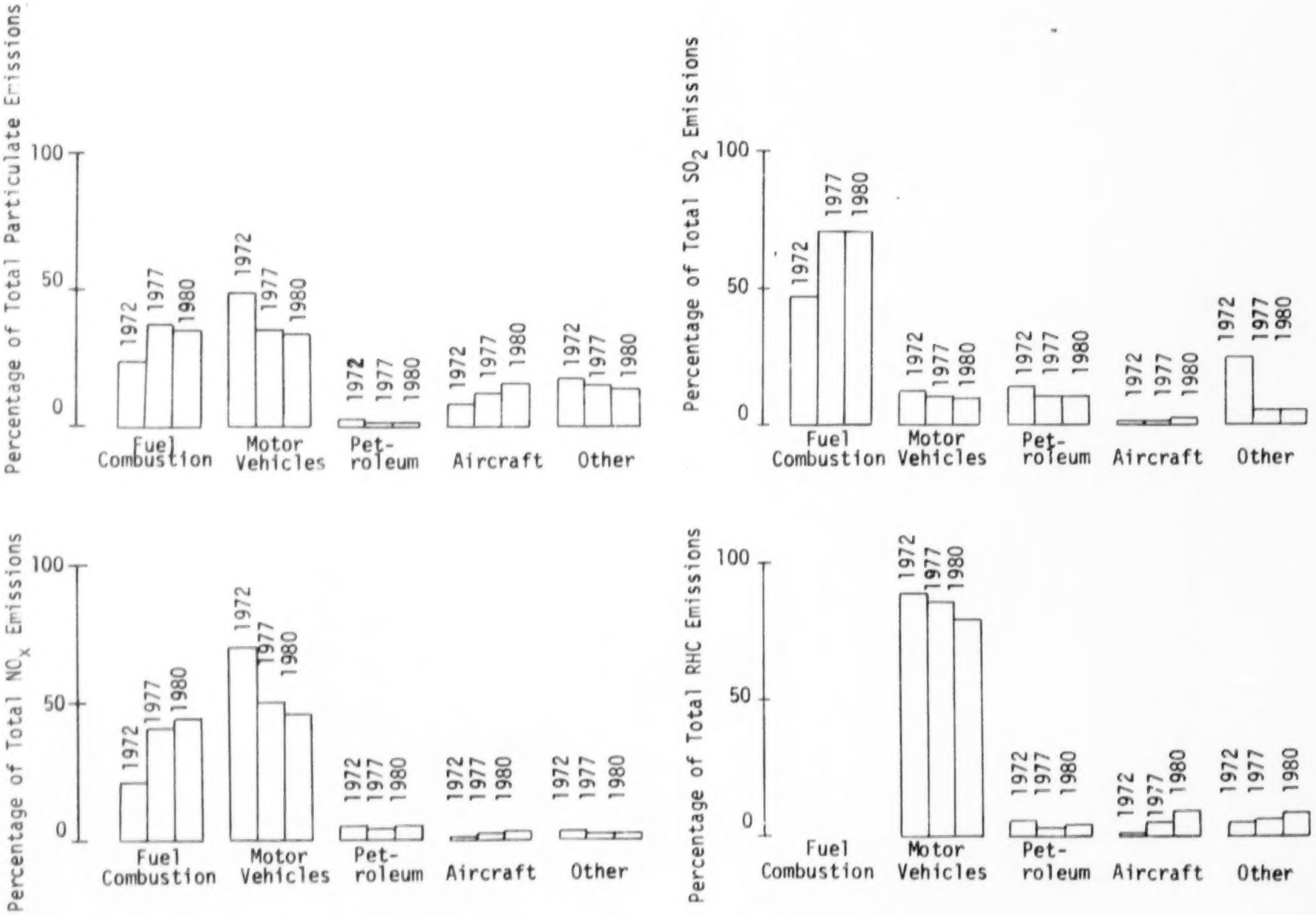


Figure 2-15. The Projected Role of the Various Major Source Categories in Emissions of Particulates and Gaseous Precursors in the Four County Area under the EPA Air Program

The methodology employed to develop the projected emission estimates (Tables 2-10 and 2-11) for each of the source categories, for both the EPA air program and the present air pollution control program, is described in the following discussion.

- Estimation of Emission Projections under Present Controls:

  Petroleum Industry Emissions. Except for Los Angeles County, all counties reporting emissions due to refining process operations are expected to have the same quantity of emissions through 1980. In Los Angeles County, emissions will change at Standard Oil and Atlantic Richfield due to construction of new facilities scheduled for completion before 1977. The effect of these new facilities on projected refinery emissions have been assessed and reported in the related environmental impact statements submitted prerequisite to the construction permit, [33]. Because of improvements in emissions control which will accompany the new construction, emissions of reactive hydrocarbon emissions will decrease by .5 tons. All other pollutant emissions will remain unchanged, except for those arising from new refinery combustion equipment, which is classified as a stationary combustion source in the emission inventory of this study.

  Reactive hydrocarbon emissions from marketing operations were projected by assuming a continuation of the historical 4% per year gasoline sales increase, and by accounting for a 90% reduction in these emissions starting in 1975 due to initiation of the Los Angeles APCD vapor recovery rule (Rule #65) targeted for gasoline service station storage tanks.

Organic Solvent Operations, Chemical Processing, Metallurgical, and Mineral Processing. The yearly growth rate of emissions was calculated by assuming it equal to the projected yearly increase in total employment for the county (see Table 2-9). An exception to this procedure was incorporated in the estimation of future emissions of SO_2 from sulfur recovery plants. These emissions were assumed constant at 10 tons/day of SO_2 over the next several years due to: (1) enforcement of Rule 53 limiting SO_2 stack concentrations, and (2) relatively constant activity expected from the recovery plant feed sources (petroleum refinery offstream gases) until 1980.

Agriculture and Incineration. Emission rates from agriculture related industries were assumed to be unchanged through 1980. Emissions due to incineration operations were assumed to increase at the same rate as the population in each county. Population projections were available from the State Population Research Unit, [34].

Stationary Fuel Combustion. Estimations for projected emissions arising from power plant fuel combustion were based on projections of emissions developed by the Southern California Edison Company. Edison has based these estimates on expected customer demands, availability of natural gas and low sulfur fuel oil, and purchased power from Edison plants outside the air basin. Emissions from Los Angeles Department of Water and Power plants were assumed to be related to their power generating capacity according to the same proportion indicated by the Edison Company projected emissions and power generation figures. Because of the Department of Water and Power's proposed policy of obtaining future additional power demands from sources outside the air basin, [35]. emissions from these plants were assumed to remain constant from 1972 through 1980.

Emissions from domestic and commercial fuel combustion equipment result from the burning of natural gas supplied by the Southern California Gas Company and the City of Long Beach. Projected gas deliveries have been estimated by each of these gas companies, [36]. Using the gas delivery projections and EPA emission factors, [26]. the average daily emissions from domestic and commercial fuel combustion were calculated.

Emissions from industrial fuel combustion equipment are generated when burning either natural gas or alternate fuels (primarily fuel oil). The "interruptible" natural gas consumption of industrial combustion units has been projected by gas suppliers, [36], for the next several years. These projections, coupled with emission factors for combustion of natural gas, permit the calculation of the portion of industrial fuel combustion emissions which arise from the burning of natural gas. The curtailment (the difference between supply and demand) of natural gas is made up by the burning of alternate fuels. Emissions generated by the burning of alternate fuels were projected to future years by scaling up the corresponding portion of the 1972 baseyear emissions with the natural gas curtailment projections (see Support Document #2,[2], for detailed explanation). Because the petroleum refineries manufacture their own supply of combustion fuels from offstream process gases, emission estimates for this source were calculated separately and added to the fuel combustion emissions calculated above. The level of projected emissions from fuel combustion at the refineries were assumed to remain constant from 1972 to 1980, except for additional emissions expected to arise from operation of new refinery facilities scheduled for completion before 1977. The magnitude of the projected emissions from fuel combustion at the new refinery facilities was extracted from the environmental impact statements associated with the new refinery projects.

Aircraft Emissions. Jet aircraft emissions were assumed to originate entirely from air carrier airports, while general aviation airports were assumed to be constituted entirely of piston aircraft activities. Jet aircraft emissions were assumed to be increased at a rate of 14% per year, the historical growth rate of passenger volume from 1960-1970,[32]. Emissions from piston engine aircraft were estimated to increase at a rate equal to the projected growth rate of piston aircraft based at the general aviation airports,[32]. The effect of federal aircraft standards, scheduled to become effective in 1979 for new turbine and piston engines, was considered to be insignificant in 1980.

Motor Vehicles. Light and heavy duty motor vehicle emissions of hydrocarbons and NO_x were projected using the standard procedure outlined in Appendix C of Support Document #2, [2]. Basically, emissions are estimated by determining the annual mileage by model distribution of the region's vehicle population, the overall anticipated mileage traveled by vehicles in the region, and then applying appropriate emission factors which are attributable to the various vehicle age classifications. The emission factors reflect the present control program and the Air Resources Board retrofit program requiring nitrogen oxide control devices on all 1966-1970 vehicles. Emissions of SO_2 and particulates were calculated on the basis of emission factors obtained from automotive exhaust studies concerning vehicles equipped with catalytic converters (see Appendix E of Support Document #2, [2]),[37]. These emission factors were applied to the segment of the motor vehicle population expected to be equipped with the converter by the year 1977 or 1980 (see Appendix D of Support Document #2, [2]). The remainder of the vehicle population was assumed to emit particulates and SO_2 at the rate assumed for the baseyear calculation.

Diesel emissions were projected by assuming them equal to the growth rate of VMT as projected by the Los Angeles Transportation Study for the Los Angeles area.

Emissions from miscellaneous uncontrolled vehicles were projected on the basis of the statewide projection to 1980 made by Automotive Environmental Systems, [29]. The projection to 1977 was calculated by a linear interpolation between 1972 and 1980 figures.

- Estimation of Emissions Projections under EPA - Promulgated Controls:

  Stationary Sources. By 1977 the EPA federal air program will require the installation of vapor recovery systems at gasoline stations and additional emission controls for organic solvent operations, [38]. The projected stationary source emission inventory after implementation of these controls is calculated by considering the emission reductions attributable to each of the control measures: an 81% reduction of reactive hydrocarbon emissions at gasoline stations, and a 33.6% reduction of emission from organic solvent users, [39].

  Motor Vehicles. Under the promulgated EPA air program, inspection/maintenance and catalytic converter retrofits are required for a major portion of the light-duty vehicle population (VMT reduction measures specified under the EPA plan were not included in this study assessment due to the current uncertainty with regard to their effectiveness and socio-economic acceptability). Projections of emissions with these control measures in effect were calculated by attributing a 15% reduction in hydrocarbon emissions from motor vehicles affected by the inspection/maintenance program, and a 50% reduction in hydrocarbon emissions from motor vehicles retrofitted with the catalytic converters. Projection of emissions of particulates and SO_2 from light duty motor vehicles retrofitted with the catalytic converter were calculated utilizing emission factors extracted from recent relevant automotive studies, [37]. The methodology of the calculation is the same as that used in deriving emissions of particulates and SO_2 from the motor vehicle population characterized under the "present control plan," which involves a lesser percentage of vehicles equipped with the converter. A detailed explanation of the projection estimates is contained in Appendix C, D, and E of Support Document #2, [2].

2.3 A METHODOLOGY FOR RELATING EMISSION LEVELS TO AMBIENT PARTICULATE AIR QUALITY

In order to formulate a systematic air quality implementation plan, a methodology is needed to translate emission level changes into air quality changes. Specific to this project, a model is required to determine how suspended particulate air quality will depend on emissions of primary particulates, SO_2, NO_x, and RHC in the Los Angeles Region. Such a model can be used to transform emission projections into air quality forecasts and to predict the atmospheric impact of various control strategies.

Support Document #3 develops the model to be used in this study, [3]. The present section summarizes the major results of that development process. The air quality - emission level model depends on two basic analyses. First, the origins of suspended particulates are identified at several locations in the Los Angeles Region, (See Section 2.3.1). Second, the dependence of the controllable (non-background) origin categories on contaminant emissions levels is determined, (Section 2.3.2.). As shown in Section 2.3.3., the air quality-emissions level model is completed by a synthesis of these two results.

2.3.1 Characterization of Aerosol Origins in the Metropolitan Los Angeles Region

The development of a systematic relationship between pollutant emissions and measured suspended particulate levels required identification of the origins of suspended particulate matter. This study employed the following classification scheme to characterize aerosol origins:

AEROSOL ORIGIN CLASSIFICATION SCHEME

I. Background Contributions	
A. Primary	Sea Salt ________________
	Soil Dust ________________
	Primary Anthropogenic Sources Exterior to the Los Angeles Region ________________
B. Secondary	Sulfate ________________
	Nitrate ________________
	Secondary Organics ________________
II. Non-Background Contributions (Anthropogenic Sources within the Los Angeles Region)	
A. Primary	Total Primary ____________
B. Secondary	Sulfate ________________
	Nitrate ________________
	Ammonium ________________
	Secondary Organics ________________

It was found that there were 12 locations in the Metropolitan Los Angeles Region with sufficient data on aerosol chemical composition to support the origin analysis. These locations are illustrated in Figure 2-16. As noted above, the origin characterization was carried out only for annual mean particulate levels, not for 24 hour maximal levels.

Estimates of Background Contributions

For the purposes of this study, the background aerosol is defined as that part of the total aerosol which is not subject to emission regulations in the Los Angeles Region. Thus, the non-background aerosol is that portion subject to direct emission control. The three main sources of background aerosol are natural sources, dust resulting from activities such as agriculture or traffic, and man-made emissions exterior to the Los Angeles Region. Water aerosol was not included in the background classification because there are indications that, unlike the ambient aerosol, equilibriated Hi-Vol samples contain negligible amounts of water, (see Support Document #1 for a discussion).

Background particulate levels may undergo significant spatial variations in the Los Angeles Region. In this study, three general areas were distinguished for the background aerosol analysis: the coastal area, the central-valley area, and the eastern-inland area, (see Figure 2-16). In the final origin characterization, adjustments were made for individual monitoring sites within these general areas, (see later, Table 2-17).

Two methods were used to estimate background aerosol levels. METHOD I derived estimates of overall background levels by reviewing total Hi-Vol measurements at several (non-urban) marine and desert locations in the Southern California area. METHOD II determined values for each specific category of background aerosol. Sulfate, nitrate, secondary organics, and man-made primary sources exterior to the Los Angeles Region were

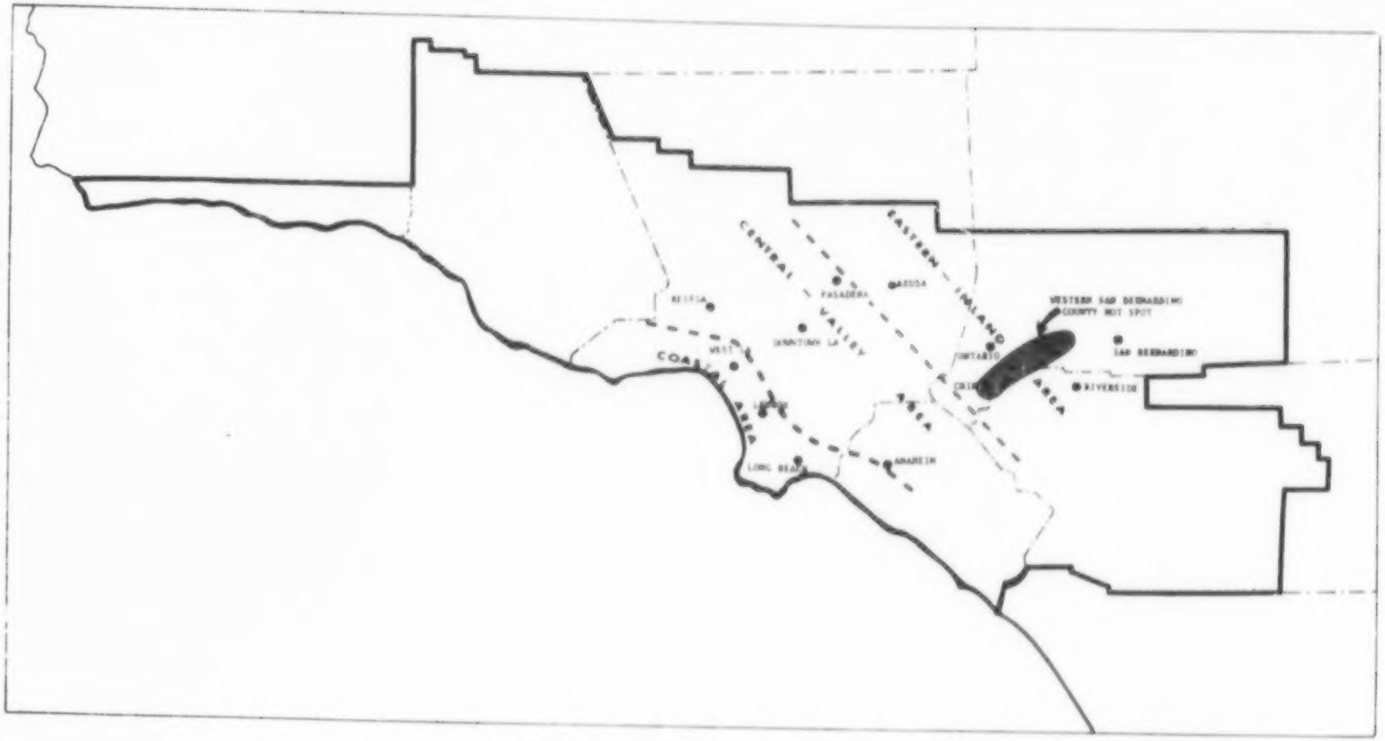

CENTRAL VALLEY AREA
EASTERN INLAND AREA
COASTAL AREA
RESEDA
PASADENA
AZUSA
DOWNTOWN LA
WEST
LENNOX
LONG BEACH
ANAHEIM
ONTARIO
CHI
WESTERN SAN BERNARDINO COUNTY HOT SPOT
SAN BERNARDINO
RIVERSIDE

Figure 2-16 Locations for the Aerosol Origin Characterization

estimated from data at the non-urban locations. The sea salt and soil dust contributions were found by applying a chemical element tracer technique to sodium and aluminum measurements taken within the Los Angeles Region. In METHOD II, the total background levels were found by adding the contributions from each sub-category. Support Document #3 to this study gives a detailed description of each of the methods.

Table 2-12 compares the background aerosol estimates obtained by the two methods. Although the variance in the estimates is large, the agreement of overall levels and of trends from coast to inland is extremely good.

In summary, total background levels in the Los Angeles Region appear to vary from around 30-40 $\mu g/m^3$ in the coastal area, to around 35-45 $\mu g/m^3$ in the central-valley area, to around 45-55 $\mu g/m^3$ in the eastern-inland area. The approximate origin breakdown for the background aerosol that was indicated by the analysis is as given in Table 2-13.

TABLE 2-12

ESTIMATES OF AVERAGE TOTAL BACKGROUND LEVELS

(ARITHMETIC MEANS)

	METHOD I ANALYSIS OF TOTAL NON-URBAN LEVELS	METHOD II BY ADDITION OF ESTIMATES FOR EACH CATEGORY IN THE CLASSIFICATION SCHEME
COASTAL AREA	30-40 $\mu g/m^3$	24-46 $\mu g/m^3$
CENTRAL-VALLEY AREA	35-50 [a]$\mu g/m^3$	27-49 $\mu g/m^3$
EASTERN-INLAND AREA	45-60 $\mu g/m^3$	35-57 $\mu g/m^3$

a. Interpolation of the Coastal and Eastern Inland Results.

TABLE 2-13

BACKGROUND AEROSOL CLASSIFICATION SCHEME FOR THE LOS ANGELES REGION

(ARITHMETIC MEANS)

SUB-AREA	APPROXIMATE TOTAL BACKGROUND LEVEL	BACKGROUND CLASSIFICATION SCHEME ($\mu g/m^3$)					
		PRIMARY			SECONDARY		
		SEA SALT	SOIL DUST	MAN-MADE SOURCES EXTERIOR TO L.A. REGION	$SO_4^=$	NO_3^-	SECONDARY ORGANICS
COASTAL	~35 $\mu g/m^3$	8	16	3	4	1	3
CENTRAL-VALLEY	~40 $\mu g/m^3$	6	23	3	4	1	3
EASTERN-INLAND	~50 $\mu g/m^3$	4	35	3	4	1	3

Hi-Vol Composition Data

In order to determine non-background contributions, data were required on Hi-Vol chemical composition within the Los Angeles Region. Specifically, measurements were needed for lead (Pb), sulfate ($SO_4^=$), nitrate (NO_3^-), ammonimum (NH_4^+), and benzene solubles (BSOL). The compositional data base was reviewed in Support Document #3, and it was found that sufficient data existed to characterize particulate composition at 12 locations in the Los Angeles Region. These locations are illustrated in Figure 2-16.

In determining annual average aerosol composition, reliance was placed on data from three long term monitoring programs: the National Air Surveillance Network (NASN), The Los Angeles APCD Network, and the San Bernardino County APCD Network. Some compositional measurements were also available fron the following monitoring projects:

- Orance County APCD Monitoring Program
- California Air Resources Board Monitoring System, [40]

- University of Southern California Study, (Gordon & Bryan [41])
- State Air Pollution Research Center Study, (Lundgren, [42])
- Air Resources Board/Rockwell International Aerosol Characterization Study, (ACHEX), (Hidy, [43])

However, the last three of these projects were just of temporary nature, and the first two supplied compositional data only for lead. Thus, the latter five projects were used only in a supplementary fashion.

At each location, the average composition measurements from the various monitoring networks were compared and analyzed. From this analysis, a percentage contribution from each constituent was determined for each location. These percentages were then applied to the 1972 expected annual average Hi-Vol levels, (as determined in Support Document #1), to yield a compositional breakdown characteristic of the 1972 base year. The results are given in Table 2-14. The interested reader is referred to Support Document #3 for the details of the analysis.

A First Iteration for the Aerosol Origin Characterization

As a first iteration, rather simplistic calculations were applied to the compositional data in order to estimate contributions from the non-background aerosol categories. Table 2-15 briefly describes these calculations. A thorough discussion is given in Support Document #3.

As shown in Table 2-16, the calculated non-background contributions were added to the background estimates to yield "accounted for" values of average Hi-Vol levels. The results of this first iteration were then compared to the actual average Hi-Vol levels at each location. For all but three locations, the relative differences between "accounted for" and actual particulate levels were less than 8%. This agreement was remarkable considering the simplicity of many of the assumptions inherent in the first

TABLE 2-14 HI-VOL PARTICULATE COMPOSITION:

CHARACTERIZATION FOR THE 1972 BASE YEAR

Location	Total Suspended Particulates µg/m³ AGM	AAM	Pb	$SO_4^=$	NO_3^-	NH_4^+	Benzene Solubles
Coastal Area Sites							
1. Lennox	135	145	6.7 (4.6%)	13.2 (9.1%)	7.4 (5.1%)	N/A	N/A
2. West LA	85	90	3.0 (3.3%)	9.3 (10.3%)	6.8 (7.6%)	N/A	N/A
3. Long Beach	95	105	2.3 (2.2%)	11.2 (10.7%)	5.6 (5.3%)	1.5 (1.4%)	10.2 (9.7%)
Central Valley Sites							
4. Downtown LA	130	140	4.1 (2.9%)	14.3 (10.2%)	11.6 (8.3%)	1.4 (1.0%)	14.0 (10.0%)
5. Pasadena	110	120	3.6 (3.0%)	12.7 (10.5%)	11.4 (9.5%)	1.2 (1.0%)	13.8 (11.5%)
6. Anaheim	95	105	2.8 (2.7%)	8.7 (8.3%)	6.5 (6.2%)	0.8 (10.8%)	--
7. Reseda	130	140	4.3 (3.1%)	12.9 (9.2%)	8.4 (6.0%)	1.4 (1.0%)	16.0 (11.4%)
Eastern Inland Area Sites							
8. Azusa	150	160	3.0 (1.9%)	15.2 (9.5%)	17.7 (11.1%)	---	---
9. Ontario	110	120	1.9 (1.6%)	10.2 (9.5%)	10.8 (9.0%)	1.0 (0.8%)	9.8 (7.8%)
10. San Bernardino	115	125	2.0 (1.6%)	12.6 (10.1%)	13.1 (10.5%)	1.0 (.8%)	11.3 (9.0%)
11. Riverside	140	150	1.8 (1.2%)	11.7 (7.8%)	15.1 (10.1%)	1.5 (1.0%)	11.0 (7.3%)
Western San Bernardino County Hot Spot							
12. Chino	200	220	2.2 (1.0%)	22.0 (10.0%)	18.0 (9.0%)	----	11 [illegible] (5.5%)

TABLE 2-15 FIRST ITERATION CALCULATION METHODS FOR NON-BACKGROUND ORIGIN CATEGORIES

Origin Category	Calculation Method
Non-Background Primary Particulates	Lead (Pb) was used as a tracer for primary particulate contributions. The total non-background primary contribution at each site was estimated by factoring the Pb concentration at that site by the ratio of total regional suspended particulate emissions to total susp. regional Pb emissions. This factor was 12.8, (See Support Document #3).
Non-Background Sulfate Contribution	Non-background sulfate was simply taken as the total sulfate measured at each site minus the estimated background level of 4 $\mu g/m^3$.
Non-Background Nitrate Contribution	Non-background nitrate was taken as the total nitrate measured at each site minus the estimated background level of 1 $\mu g/m^3$.
Non-Background Ammonium	Non-background ammonium was taken as total ammonium minus the estimated background level of .3 $\mu g/m^3$.
Non-Background Secondary Organics	A method using benzene soluble data along with estimates for the solubility of both primary and secondary organics did not yield sensible results. Thus, as a first approximation, an educated conjecture was made that non-background secondary organic levels were 10, 20, and 30 $\mu g/m^3$ in the coastal, central-valley, and eastern-inland areas respectively.

TABLE 2-16 AEROSOL ORIGIN CHARACTERIZATION -- FIRST ITERATION

(ANNUAL ARITHMETIC MEAN -- $\mu g/m^3$)

LOCATION	APPROXIMATE BACKGROUND AEROSOL Natural Contribution, Suspended Dust, and Man-made Sources Exterior to the L.A. Region	NON-BACKGROUND CONTRIBUTIONS (Anthropogenic, excluding suspended dust and sources exterior to the Los Angeles Region)					ACCOUNTED FOR ANNUAL MEAN	TOTAL 1972 ANNUAL MEAN	RELATIVE DIFFERENCE
		PRIMARY	$SO_4^=$	NO_3^-	NH_4^+	SECONDARY ORGANICS			
COASTAL AREA									
1. Lennox	35	86	9	6	1	10	147	145	+1%
2. West Los Angeles	35	38	5	6	1	10	95	90	+6%
3. Long Beach	35	29	7	5	1	10	87	105	-17%
CENTRAL-VALLEY AREA									
4. Downtown Los Angeles	40	52	10	11	1	20	134	140	-4%
5. Pasadena	40	46	9	10	1	20	126	120	+5%
6. Anaheim	40	36	5	6	1	20	108	105	+3%
7. Reseda	40	55	9	7	1	20	132	140	-6%
EASTERN-INLAND AREA									
8. Azusa	50	38	11	17	1	30	147	160	-8%
9. Ontario	50	24	6	10	1	30	121	120	+1%
10. San Bernardino	50	26	9	12	1	30	128	125	+2%
11. Riverside	50	23	8	14	1	30	126	150	-17%
WESTERN SAN BERNARDINO COUNTY HOT-SPOT									
12. Chino	50	28	18	17	1	30	144	220	-35%

iteration calculations. For the locations with larger relative differences, such as Chino, Long Beach, or Riverside, there were apparent reasons why some of the simplistic assumptions were not appropriate. These reasons are discussed in Support Document #3.

Completion of the Aerosol Origin Characerization

In order to formulate a systematic model for the relationship between pollutant emissions and ambient particulate levels, the total particulate level at each location should be fully accounted for by the origin classification scheme. Thus, as a second and final characterization, the origin contributions in the first iteration were adjusted so that the total particulate levels at each site were fully accounted for. The adjustments were made in the most uncertain origin classes: the background, non-background primary, and non-background secondary organic categories. The other categories represented direct measurements and were not adjusted. The rationale behind the adjustments is discussed in Support Document #3. Large changes were made with distinct reasons, but some small changes were rather arbritary. The only locations that required large alterations were Long Beach, Riverside, and Chino.

Table 2-17 presents the complete origin characterization for the twelve locations in the Metropolitan Los Angeles Region. Although an attemp was made to derive the best origin characterization that is possible with existing data, there is still considerable uncertainity in many of the values given in Table 2-17. It is difficult to perform a quantitative error analysis of the results; however, a subjective indication of the error level is useful in interpreting the results. The most uncertain category is non-background secondary organics; the error may be as high as 20 to 40%. The other categories, (total background, non-background primary,

TABLE 2-17 ORIGIN CHARACTERIZATION FOR ANNUAL MEAN HI-VOL PARTICULATE LEVELS ($\mu g/m^3$)

LOCATION	BACKGROUND CONTRIBUTIONS						TOTAL BACK-GROUND	NON-BACKGROUND CONTRIBUTIONS (Anthropogenic Sources within LA Region)					TOTAL AAM
	PRIMARY			SECONDARY				PRIMARY	SECONDARY				
	Sea Salt	Suspended Dust	Primary Man-made Sources Exterior to the L.A. Region	$SO_4^=$	NO_3^-	Secondary Organics			$SO_4^=$	NO_3^-	NH_4^+	Secondary Organics	
COASTAL AREA LOCATIONS													
1. Lennox	8	16	3	4	1	3	35	84	9	6	1	10	145
2. West Los Angeles	8	14	3	4	1	3	33	36	5	6	1	9	90
3. Long Beach	8	16	3	4	1	3	35	47	7	5	1	10	105
CENTRAL-VALLEY AREA LOCATIONS													
4. Downtown Los Angeles	6	27	3	4	1	3	44	54	10	11	1	20	140
5. Pasadena	6	21	3	4	1	3	38	42	9	10	1	20	120
6. Anaheim	6	23	3	4	1	3	40	36	5	6	1	17	105
7. Reseda	6	26	3	4	1	3	43	58	9	7	1	22	140
EASTERN-INLAND AREA LOCATIONS													
8. Azusa	4	38	3	4	1	3	53	41	11	17	1	37	160
9. Ontario	4	34	3	4	1	3	49	24	6	10	1	30	120
10. San Bernardino	4	33	3	4	1	3	48	26	9	12	1	29	125
11. Riverside	4	45	3	4	1	3	60	30	8	14	1	37	150
WESTERN SAN BERNARDINO COUNTY HOT SPOT													
12. Chino	4	45	3	4	1	3	60	89	18	17	1	35	220

sulfate, nitrate, and ammonium), are better documented. The error in these categories should be on the order of 10 to 20%.

Figures 2-17 through 2-20 presents the spatial distribution of the most significant origin categories. It can be seen that background aerosol and non-background nitrate and secondary organics increase with distance inland. Non-background sulfate shows no consistent spatial trend. The non-background primary contribution generally decreases with distance inland. Support Document #3 shows that these trends can be explained by the source distribution and meteorology of the Los Angeles Region.

2.3.2 The Dependence of Suspended Particulate Levels on Contaminant Emissions

In the previous section, the portion of the Los Angeles aerosol that is subject to direct emission control in the Los Angeles Region was classified as non-background. Non-background particulates were subdivided according to the following origin categories:

- Non-background primary particulates
- Non-background secondary particulates
    - Sulfates
    - Nitrates
    - Ammonium
    - Secondary Organics

Having identified the contributions from these controllable origin categories, the final step in determining the relationship between emissions and air quality is to find the dependence of each origin category on emission levels. In Support Document #3, the existing theoretical and empirical

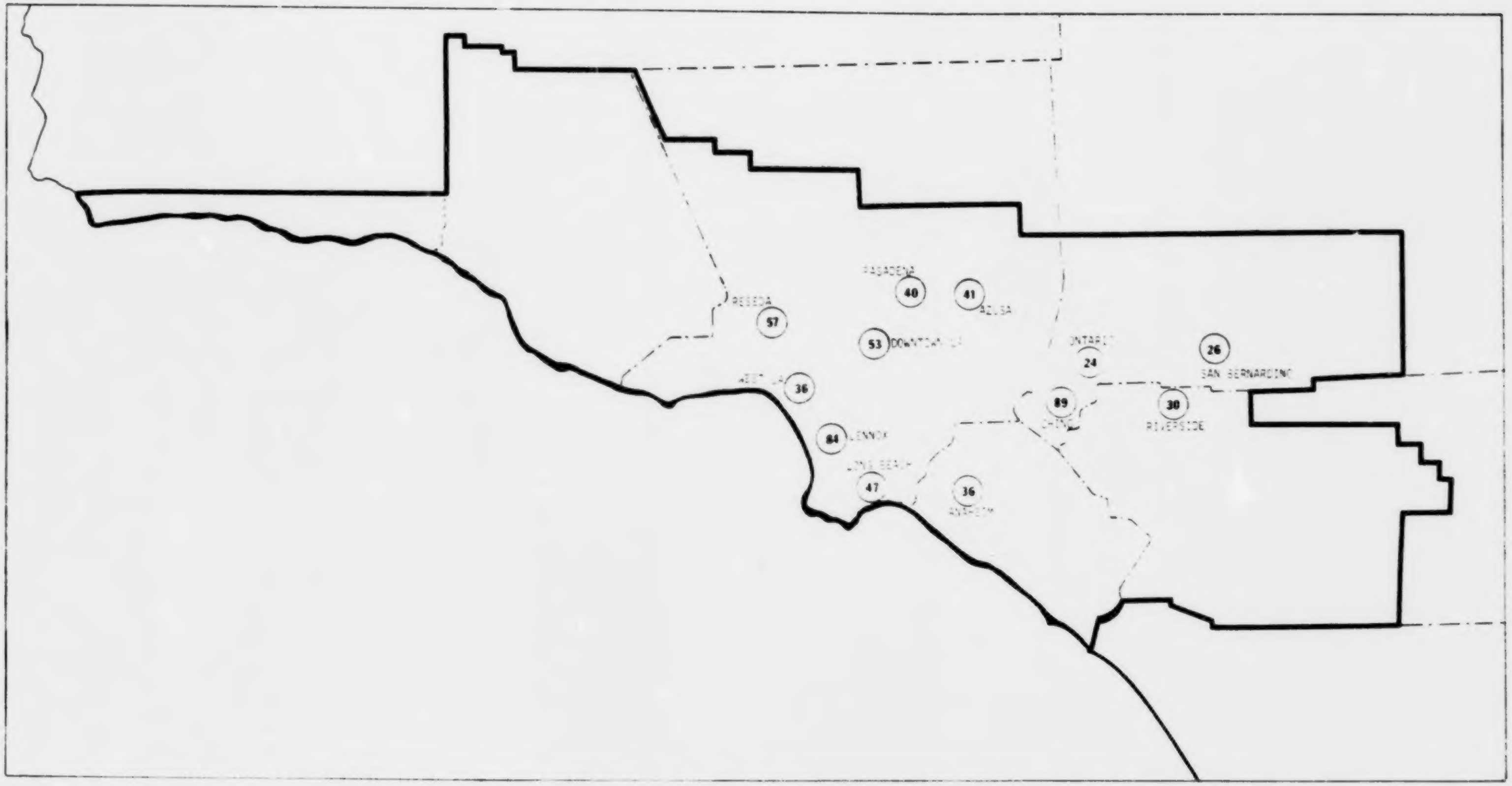

PASADENA
40
41
AZUSA
RESEDA
57
53
DOWNTOWN LA
ONTARIO
24
26
SAN BERNARDINO
WEST LA
36
89
CHINO
30
RIVERSIDE
84
LENNOX
LONG BEACH
47
36
ANAHEIM

Figure 2-17 Estimated Non-Background Primary Particulate Levels in the Los Angeles Region

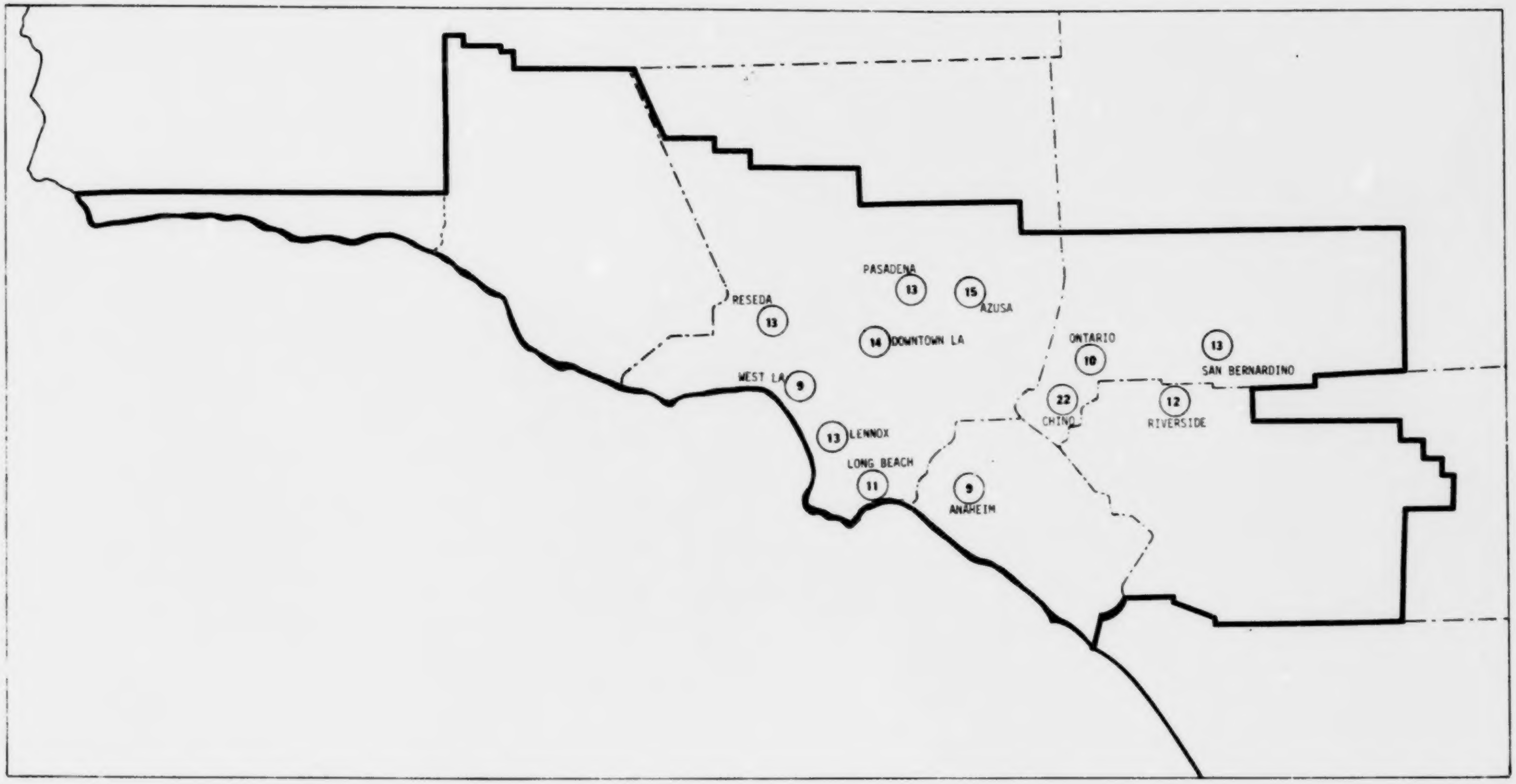

PASADENA
13
15
AZUSA
RESEDA
13
14
DOWNTOWN LA
ONTARIO
10
13
SAN BERNARDINO
WEST LA
9
22
CHINO
12
RIVERSIDE
13
LENNOX
LONG BEACH
11
9
ANAHEIM

Figure 2-18 Total Sulfate Levels in the Los Angeles Region

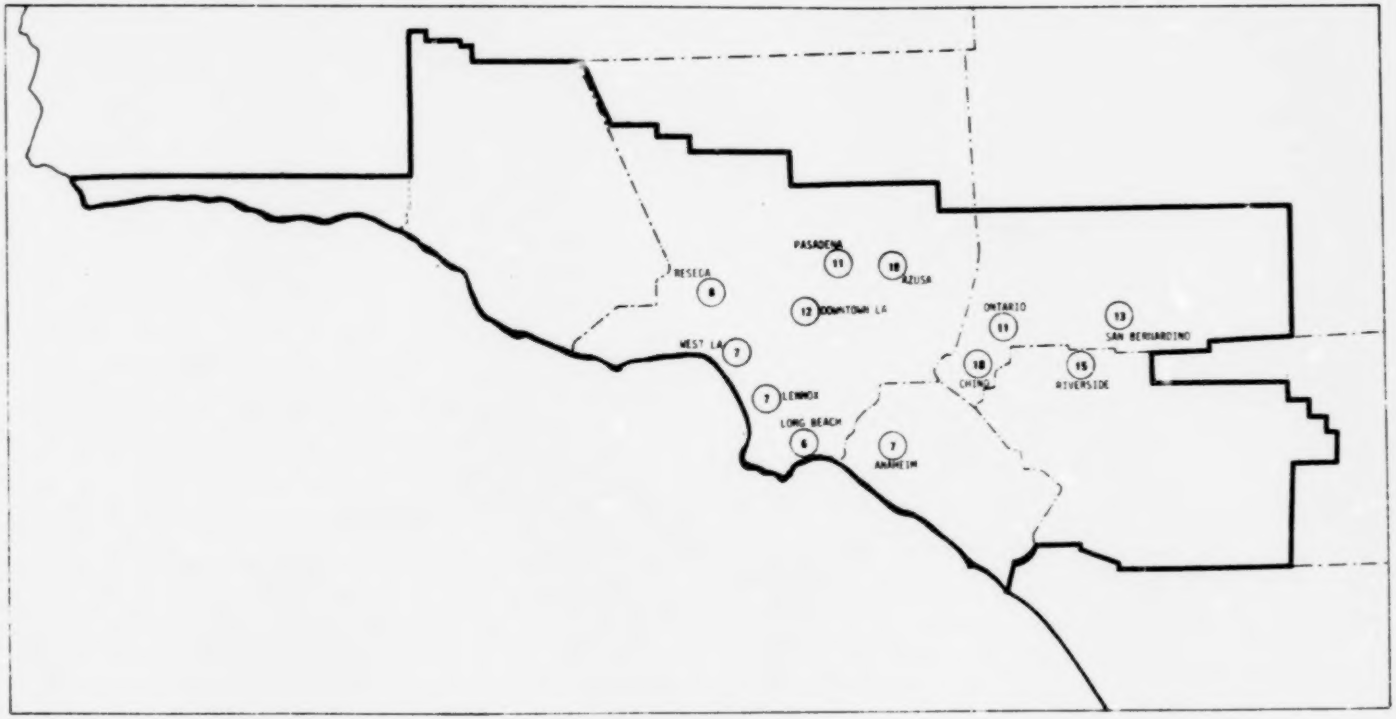
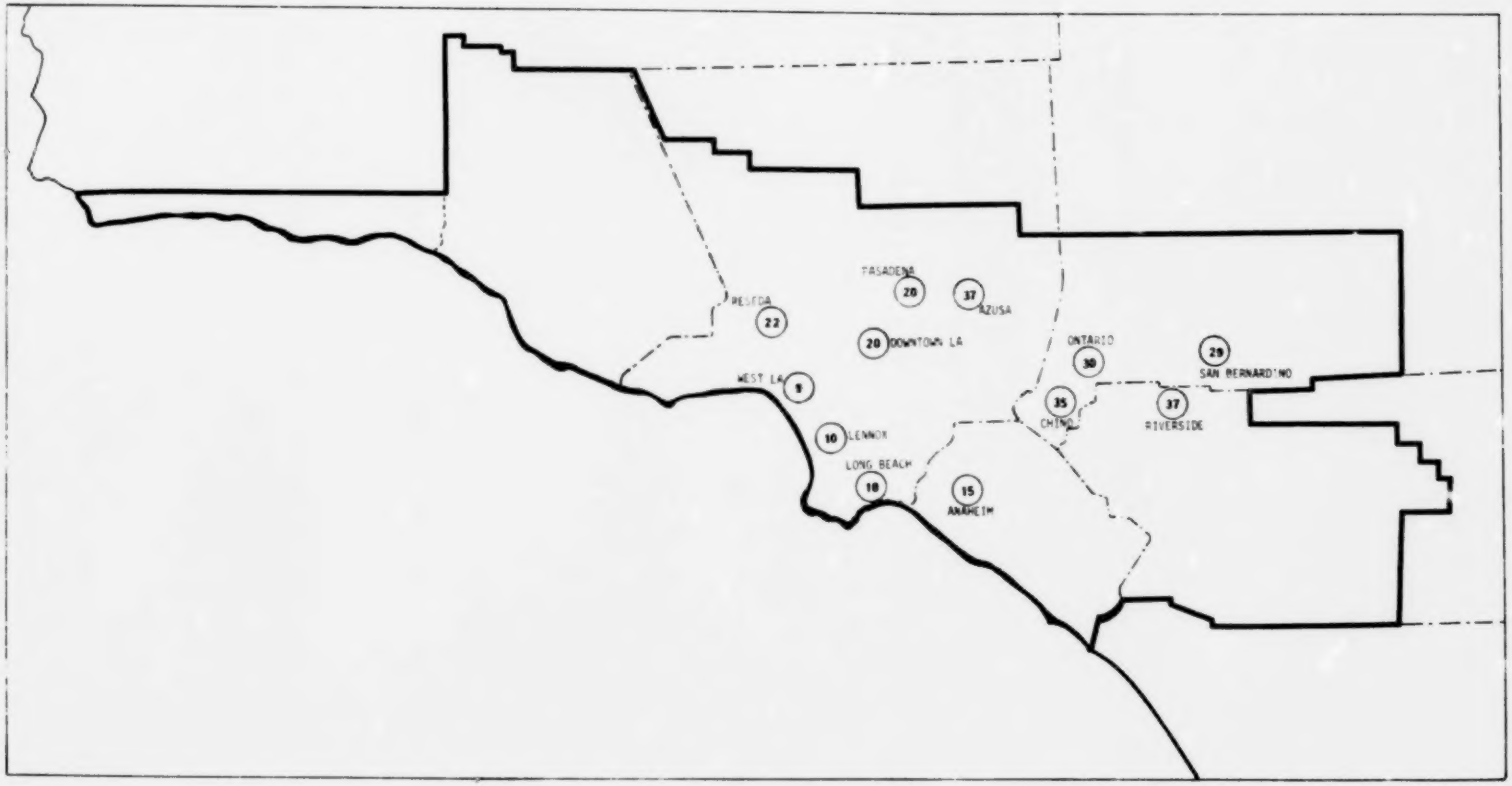

PASADENA
11
10
AZUSA
RESEDA
8
12
DOWNTOWN LA
WEST LA
7
7
LENNOX
LONG BEACH
6
7
ANAHEIM
ONTARIO
11
18
CHINO
13
SAN BERNARDINO
15
RIVERSIDE

Figure 2-19 Total Nitrate Levels in the Los Angeles Region



PASADENA
20
37
AZUSA
RESEDA
22
20
DOWNTOWN LA
ONTARIO
30
29
SAN BERNARDINO
WEST LA
9
35
CHINO
37
RIVERSIDE
10
LENNOX
LONG BEACH
10
15
ANAHEIM

Figure 2-20 Estimated Non-Background Secondary Organic Levels in the Los Angeles Region

evidence pertaining to this dependence was reviewed for each origin category. The results of this review will be summarized below. In general, it was found that a great deal of uncertainty surrounds the dependence of suspended particulates on emission levels, particularly with regard to secondary aerosol levels and gaseous precusor emissions. In the end, the linear rollback formula was chosen for primary particulates, and a similar linear form was assumed for each of the sulfate/SO_2, nitrate/NOx, and organic/RHC relationships.

Air Quality Relationship for Non-background Primary Particulates

The simple "linear rollback" technique was chosen to provide the air-quality/emission-level relationship for primary particulates. That is, non-background primary particulate levels at each location were taken as directly proportional to total primary suspended particulate emissions from man-made sources in the region.* Expressed mathematically,

$$\frac{NBPSP_i(E)}{NBPSP_i(E_o)} = \frac{E}{E_o} ,$$

where

$NBPSP_i$ = non-background primary suspended particulate level at location "i",

E = total primary suspended particulate emissions from anthropogenic sources in the region,

and the subscript "o" refers to base year values.

The applicability of the linear rollback formula to inert primary contaminants is supported by the linearity of the equation of advective diffusion with one main proviso. The proviso is that the space and time distribution of emissions does not change when the total emission level goes from E_0 to E. As discussed in Support Document #3, the assumption of fixed emission spatial pattern should be fairly well met by the control strategies to be proposed in this study. The main factor changing primary particulate emissions will be large reductions from the control of all significant source categories. This should approximate a homogeneous change fairly well. The error in the linear rollback assumption for primary particulates should be one relatively small compared to other sources of uncertainty in this study.

---

*As noted later, a modified form of this relationship was chosen for application at the Chino location which is strongly influenced by local sources.

Sulfate Air Quality Relationship

The relationship between sulfur dioxide emissions and ambient sulfate levels has been the subject of considerable research, much of which is still in progress. Support Document #3 reviewed the current state of knowledge. It was found that the oxidation of SO_2 to form sulfate is a very complex process and that considerable uncertainty still exists concerning the $SO_2/SO_4^=$ relationship.

In Support Document #3, the form of the $SO_2/SO_4^=$ relationship was first analyzed by considering known aspects of the chemical transformation processess. A review of the literature and of current research revealed that several possible avenues have been identified which can oxidize atmospheric SO_2 to yield sulfate aerosol. The three main avenues which appear to be significant are 1) photochemically induced oxidation of SO_2 to SO_3 in the gas phase with subsequent reactions yielding sulfuric acid and sulfates, 2) absorption of SO_2 in aqueous droplets with subsequent catalytic oxidation, and 3) adsorption of SO_2 on solid particules with subsequent reaction with adsorbed oxygen. These chemical transformation mechanisms and the atmospheric factors which affect the reaction rates were described in Support Document #3.

Theoretical analyses indicated that, at low SO_2 levels, the sulfate yield would be directly proportional to SO_2 input for all three mechanisms. For higher SO_2 levels, one would expect that the sulfate yield would become less than proportional to SO_2 input. This expected dependence is illustrated for a hypothetical experiment and for a hypothetical air basin in Figure 2-21. Unfortunately, the specific SO_2 level at which nonlinear effects become important has not been established from analyses of the chemical reaction processes.

A second approach used in Support Document #3 to investigate the $SO_2/SO_4^=$ relationship involved the empirical analysis of actual atmospheric data. One empirical method that was tried relied on historical data for measured ambient sulfates and for estimated SO_2 emissions, (see Figure 2-22). However, it was found that this method could not yield a systematic $SO_2/SO_4^=$ relationship from existing data due to the limited range of recent historical SO_2 emission levels and due to the meteorological fluctuations inherent in yearly $SO_4^=$ levels.

A second empirical method involved ambient measurements for both SO_2 and $SO_4^=$. The most comprehensive study of this type was performed by Altshuller on nationwide NASN data, [45], (see Figure 2-23). In Support Document #3, this method was also applied to data for the Los Angeles Region, (see Figure 2-24). In the Los Angeles application, the data were distinguished as to distance inland in order to decrease the variance from different SO_2 residence times. The Altshuller results and the Los Angeles data appeared to indicate an initial linear increase of $SO_4^=$ with SO_2, followed by a leveling off of $SO_4^=$ at higher SO_2 levels.

FIGURE 2-21a Hypothetical Experiment

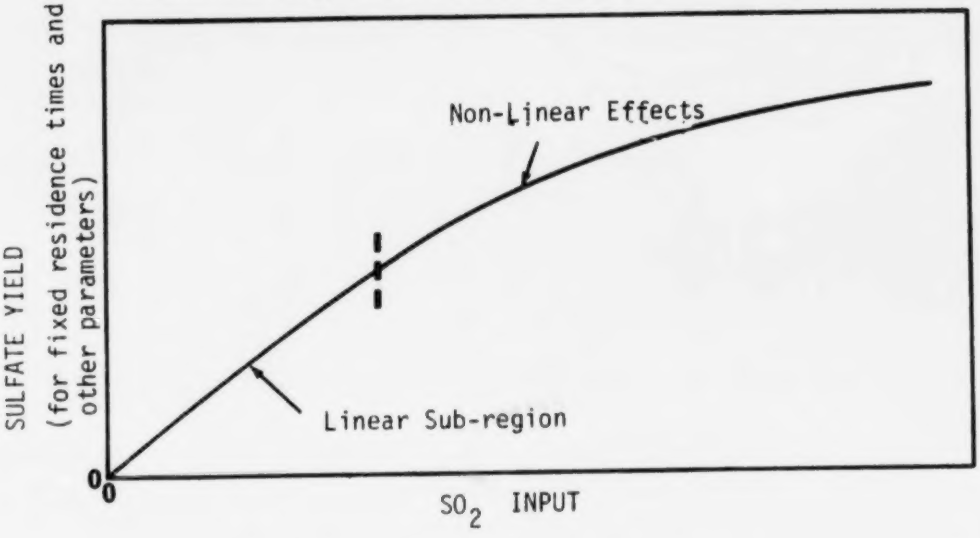


FIGURE 2-21b Hypothetical Air Basin

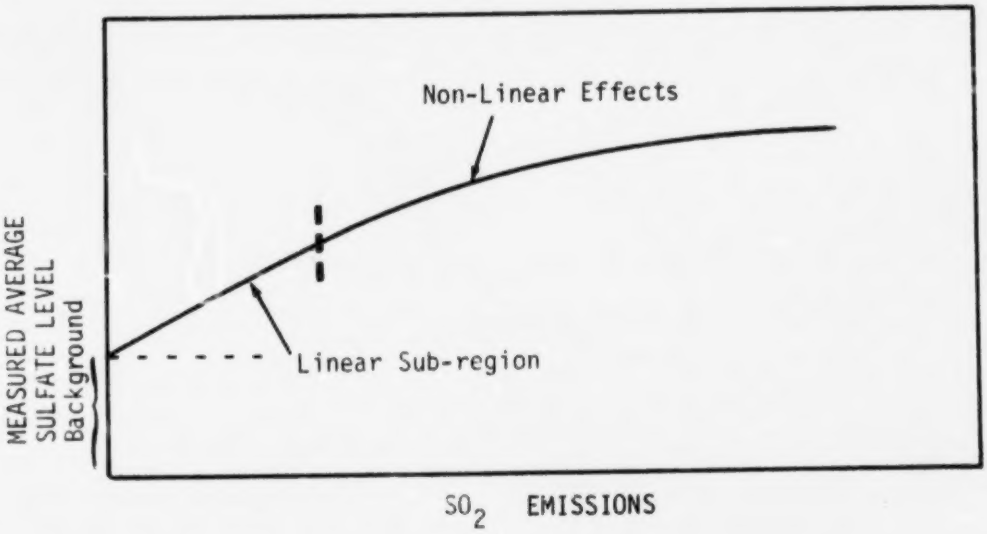
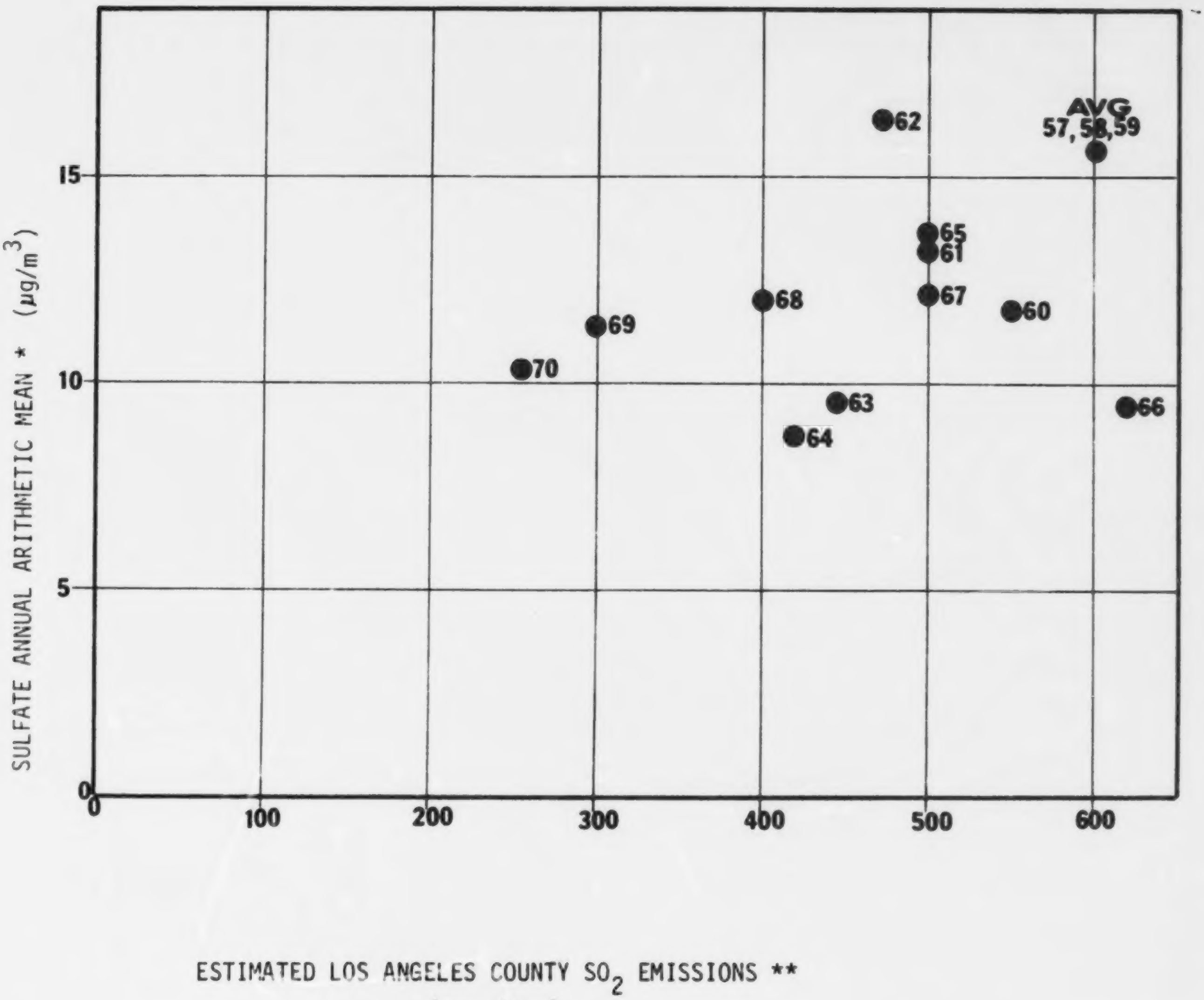


Figure 2-21 Schematic Illustration of the Dependence of Sulfate Levels on SO_2 Input



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* Average of NASN values for Los Angeles, Burbank, Glendale, Long Beach and Pasadena. Prior to 1967 data are available for at most three stations during any given year, and the available sites changed from year to year. Since all stations demonstrated the same general sulfate level, around 10-12 ug/m^3, averages were taken of all available data.

** Los Angeles County Air Pollution Control District, Reference [44].

Figure 2-22 Historical Relationship Between SO_2 Emissions and $SO_4^=$ Concentrations -- Los Angeles County, 1957 to 1970

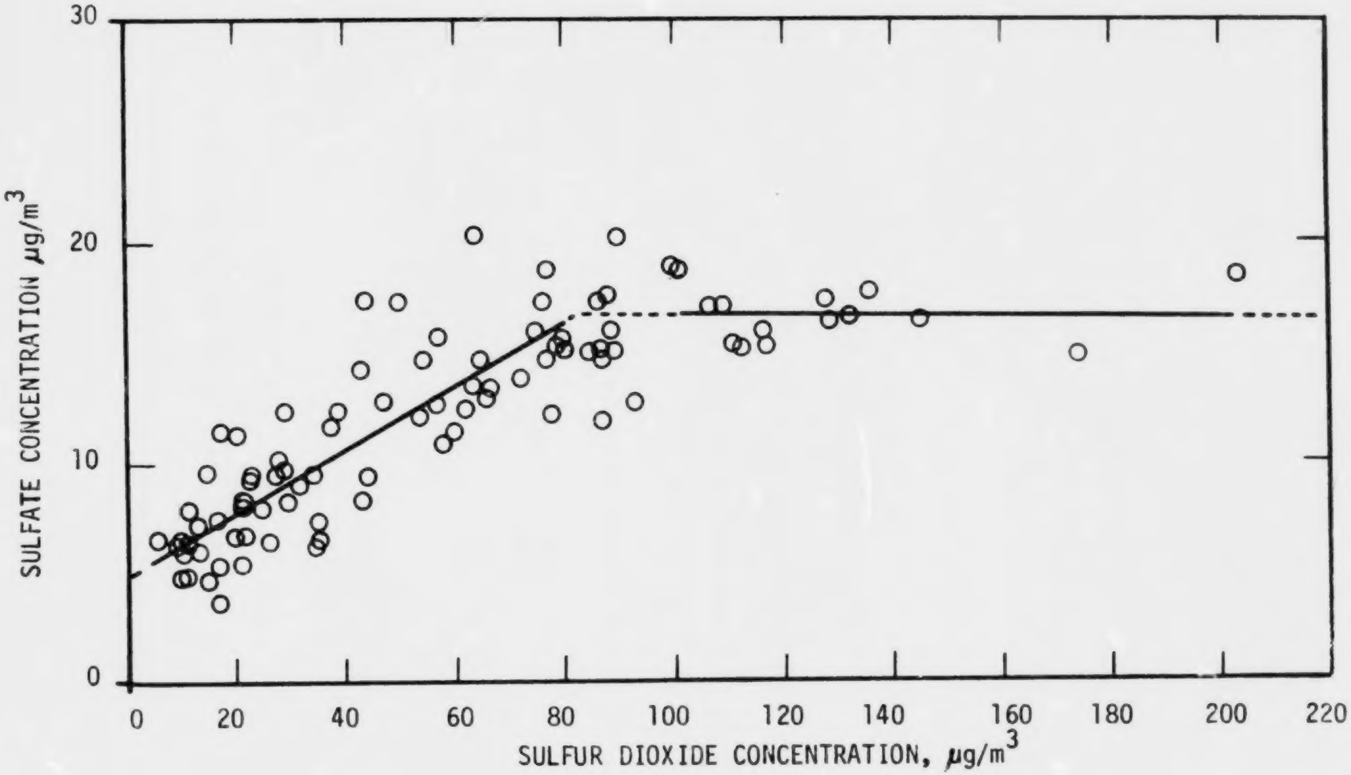
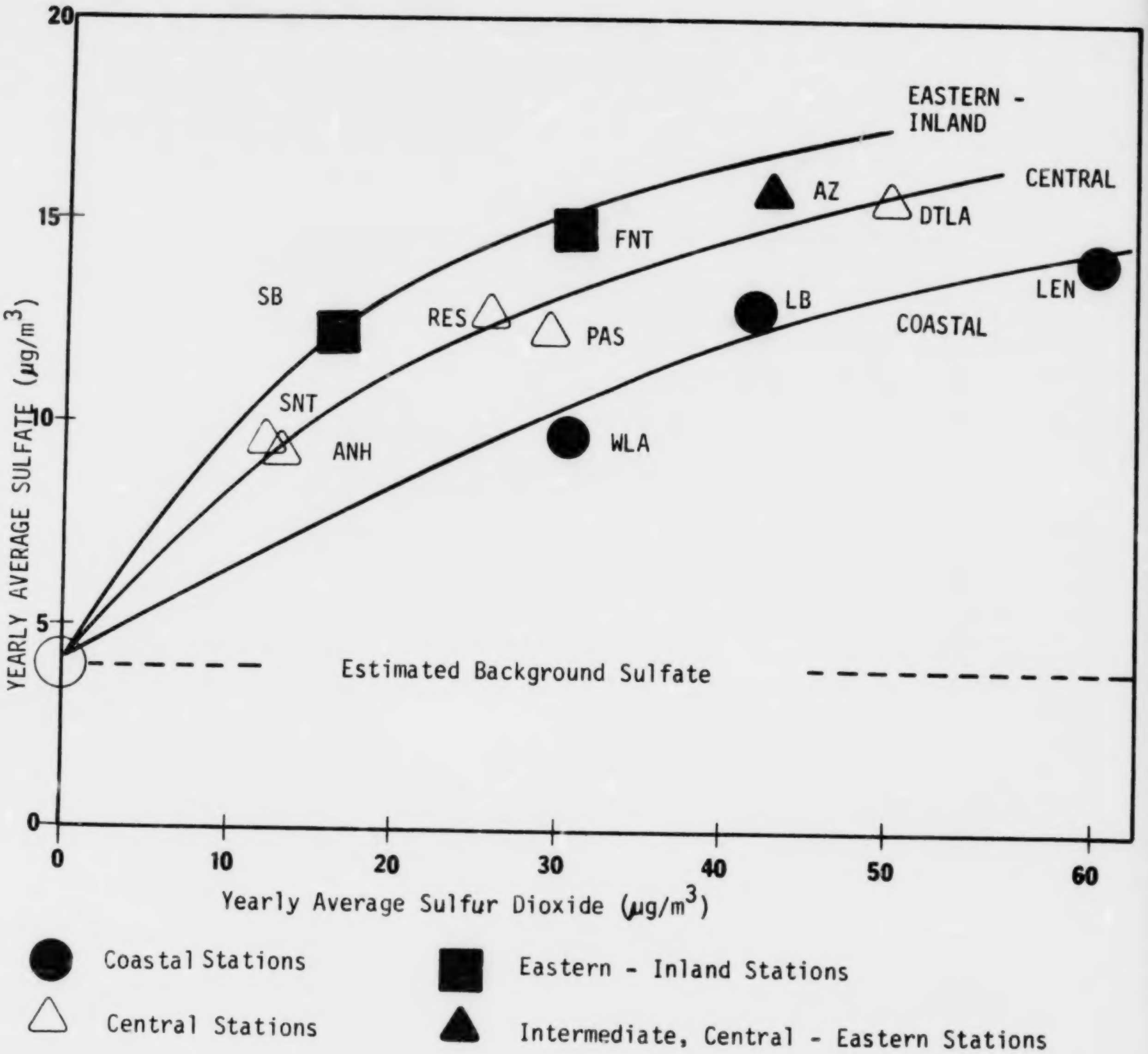


Figure 2-23 Sulfur Dioxide/Sulfate Relationship for 18 U. S. Cities

REFERENCE: Altshuller [45].



DATA SOURCES:

WLA - West Los Angeles (LA APCD 1969-1972)*
LB - Long Beach (NASN 1968 - 1970)
LEN - Lennox (LA APCD 1969-1972)*
SNT - Santa Ana (NASN 1969)
ANH - Anaheim (NASN 1969)
RES - Reseda (LA APCD 1969-1972)*
PAS - Pasadena (LA APCD 1972)*
DTLA - Downtown Los Angeles (LA APCD 1969-1972)*
SB - San Bernadino (SB APCD 1972 & NASN 1968-1969)
FNT - Fontana (SB APCD 1972)
AZ - Azusa (LA APCD 1972)*

---

* Los Angeles APCD SO_2 data have been corrected to allow for systematic round off error; the LA APCD reports all SO_2 values from 0 to .015 ppm as .01 ppm.

Figure 2-24 Aerometric Relationship Between Sulfate and Sulfur Dioxide in the Metropolitan Los Angeles AQCR

Both the analysis of chemical transformation processes and the empirical methods yielded the same qualitative conclusion. In response to SO_2 emissions, sulfate levels initially increase above background in a linear way. Gradually, nonlinear effects become important, and further increases in sulfate are less than linear.

For the purpose of simplicity in control strategy evaluation for the Los Angeles Region, a linear relation between ambient sulfate aerosol and SO_2 emissions was adopted. The assumption was that measured sulfate, minus the estimated $4\mu g/m^3$ background level, is linearly proportional to SO_2 emissions. Support Document #3 examined the potential error in the linearity assumption and concluded that the error in predicted sulfate levels might be around 10-30%. However, since sulfate represents only about 10% of the total aerosol mass, the error in total predicted particulate levels would amount to only 1 to 3%. This is quite small compared to some other uncertainties involved in the present study. Also, some of the error due to the neglect of the nonlinear sulfate/SO_2 dependence may be offset by an opposite error due to neglect of the synergistic impact from expected decreases in HC and NO_x levels, (see Support Document #3 for a discussion).

Nitrate Air Quality Relationship

Support Document #3 also examined the dependence of ambient inorganic* nitrate levels in NO_x emission levels in the Los Angeles Region. This problem directly parallels the issue of the sulfate --SO_2 dependence. Although considerable uncertainty surrounds the relationship between sulfate levels and SO_2 emissions, it was found that even less is known for the case of the nitrate -- NO_x relationship. The nitrate problem appears to be a more difficult one to solve, and to compound the trouble, less research effort seems to have been devoted to the nitrate issue.

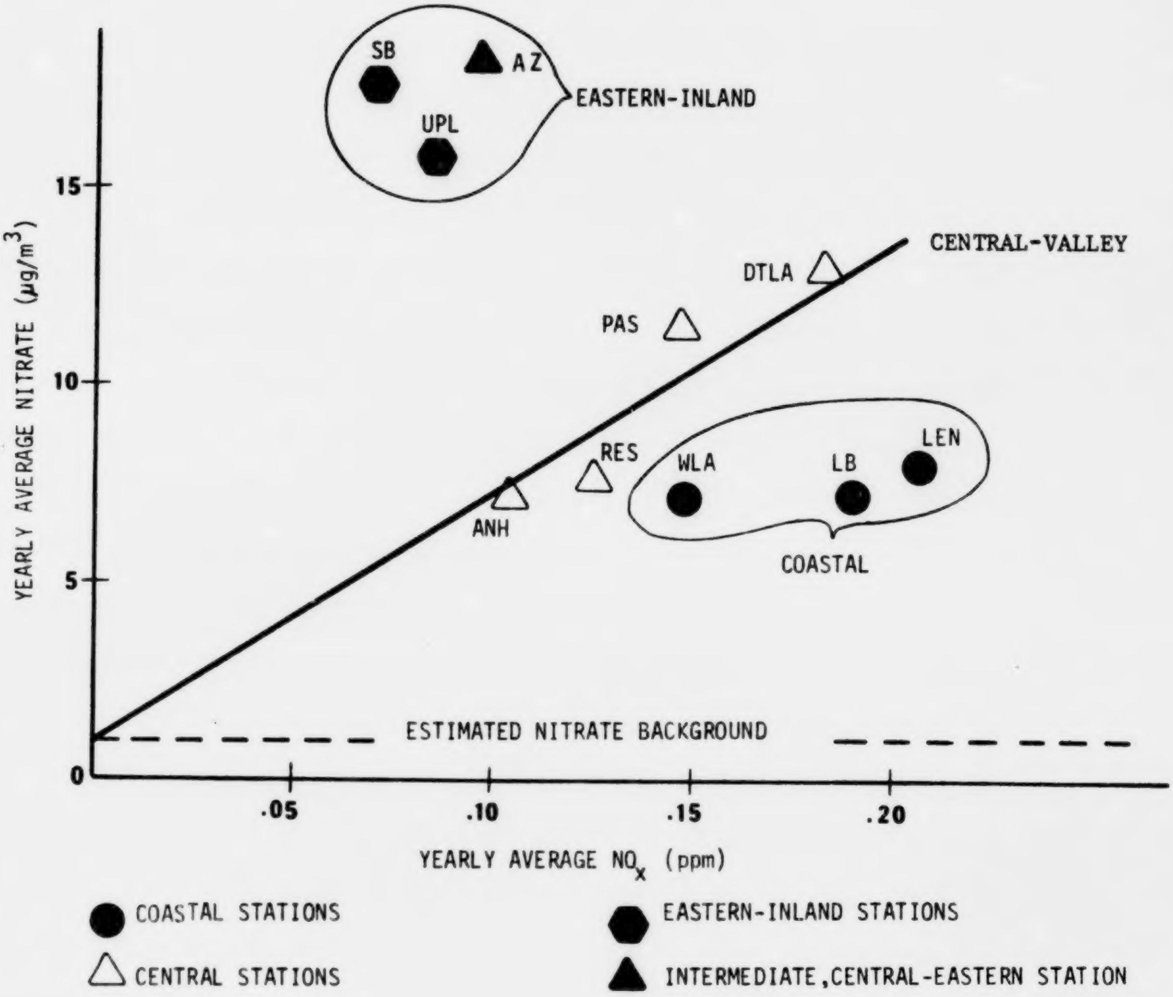
---

* In the aerosol classification scheme used by this study, organic nitrates are included in the secondary organic category.

It is not now possible to build a sound theoretical case for the form of the nitrate -- NO_x relationship because the significant conversion mechanisms have not been defined and documented. Although there is evidence that photochemical processes are important, the explicit photochemical (or other) reactions involved in nitrate production are not well understood.

In the absence of grounds for a systematic theoretical argument, Support Document #3 explored the empirical approach based on atmospheric monitoring data. Again, it was found that less work has been done with nitrates than with sulfates. No empirical study has been published for NO_3^- -- NO_x that is equivalent to Altshuller's work with $SO_4^=$ -- SO_2 (see Figure 2-23). An attempt was made in the Support Document to perform an empirical analysis using aerometric data from the Los Angeles Region (see Figure 2-25). However, the results were inconclusive. For the coastal and eastern-inland locations, the spread in NO_x levels was not wide enough to justify inferences about the NO_3^- -- NO_x relationship. For the central-valley stations, a straight line to the estimated NO_3^- background level fit well, but four data points are not sufficient to support a firm conclusion concerning linearity.

In summary, that existing knowledge concerning the dependence of NO_3^- concentrations on NO_x emissions is very poor. Neither theoretical nor empirical analysis can presently justify sound conclusions as to the



DATA SOURCE:

WLA	West Los Angeles	(LA APCD, 1969-72)
LB	Long Beach	(LA APCD - NOx, NASN-NO_3^-, 1969-70)
LEN	Lennox	(LA APCD, 1969-72)
DTLA	Downtown Los Angeles	(LA APCD, 1969-72)
PAS	Pasadena	(LA APCD, 1972)
RES	Reseda	(LA APCD, 1969-72)
ANA	Anaheim	(Orange APCD-NOx, NASN-NO_3^-, 1969-70)
AZ	Azusa	(LA APCD, 1972)
SB	San Bernardino	(San Ben., APCD, 1972-73)
UPL	Upland	(San Ben., APCD, 1972-73)

Figure 2-25 Aerometric Relationship Between Nitrate and NO_x in the Metropolitan Los Angeles AQCR

form of the NO_3^---NO_x relationship. It was decided to assume the simplest relationship: non-background nitrate (total nitrate minus 1 μg/m^3 background*) was taken as directly proportional to total NOx emission levels. There is considerable uncertainty in the use of this linear rollback formula; the principal justification is that there was no firm evidence to support the use of any specific nonlinear relationship.

Ammonium Air Quality Relationship

Support Document #3 defined non-background ammonium aerosol as that which is associated with non-background sulfate and nitrate. The air quality relationship for non-background ammonium was taken as simple linear rollback based on control of non-background sulfate and nitrate. Since non-background ammonium is such a small fraction of total suspended particulate levels, (about 1 μg/m^3), the prediction of total particulate levels should be highly insensitive to errors in the assumed NH_4^+ air quality relationship.

Secondary Organic Air Quality Relationship

The current state of knowledge concerning the relationship between secondary organic levels and reactive hydrocarbon (RHC) emissions was briefly reviewed in Support Document #3. It was found that present information cannot support any firm conclusions as to the form of the dependence. It is not possible to base the relationship upon a theoretical analysis of the reactions involved because the chemical reactions are not well understood. Empirical models based on air monitoring data appear to be ruled out because existing aerometric data are very deficient for both the precursor (reactive hydrocarbons) as well as the end product (secondary organic aerosol). Recent smog chamber studies seem to indicate a linear-proportional relationship between total aerosol formation and HC input; but this conclusion is still indefinite. These experiments also indicate a very complex nonlinear effect when the composition of HC mixtures is changed.

---

*See Table 2-13

It was decided to assume a linear-proportional relationship for the dependence of non-background secondary organic aerosol levels on RHC emissions. The accuracy of this assumption is very uncertain; there are no firm theoretical or atmospheric results which support the proportional formula for secondary organics. The main justification for the linear rollback formula is that is is the simplest and most obvious one to assume until more evidence is gathered.

2.3.3 Illustration of the Complete Model

Section 2.3.2 characterized the origins of annual average particulate levels at twelve locations in the Metropolitan Los Angeles Region. Section 2.3.3 provided (linear) relationships linking the contributions from controllable origin categories to contaminant emission levels. By combining these results, we obtain a model that yields the annual arithemetic average particulate level at each location as a function of total emission levels in the Los Angeles Region.

Table 2-18 illustrates the application of the complete model. The left side of Table 2-18 presents the 1972 origin classification for an example location, Downtown Los Angeles. The center column of the table outlines a hypothetical control strategy for primary particulates, SO_2, NO_x, and RHC. The right side of the table gives the predicted impact of the control strategy. In this hypothetical case, the 140 $\mu g/m^3$ AAM in 1972 would be reduced to 78 $\mu g/m^3$ by the control strategy.

TABLE 2-18 HYPOTHETICAL ILLUSTRATION OF THE MODEL FOR PREDICTING CONTROL STRATEGY IMPACT ON PARTICULATE AIR QUALITY LEVELS

Origin Categories	1972 Base Year Origin Characterization for Downtown Los Angeles $\mu g/m^3$	Hypothetical Control Strategy (% Reduction from the 1972 Base Year Level)	Air Quality Resulting from the Control Strategy ($\mu g/m^3$)
BACKGROUND CONTRIBUTIONS (Sea Salt, Soil Dust, Man-Made Sources exterior to the L.A. Region, and Background $SO_4^=$, NO_3^-, and Secondary Organics)	44		44
NON-BACKGROUND CONTRIBUTIONS			
PRIMARY------------	54	67% Reduction in Primary Particulate Emissions →	18
SECONDARY:			
$SO_4^=$ ------------	10	50% Reduction in SO_2 Emissions →	5
NO_3^- ------------	11	50% Reduction in NO_x Emissions →	5½
NH_4^+ ------------	1	50% Reduction in SO_2 & NO_x →	½
Secondary Organics	20	75% Reduction in RHC Emissions →	5
TOTAL AAM	140 $\mu g/m^3$	→	78 $\mu g/m^3$

A Special Case: Chino

In this study, the model will be applied as illustrated above to each location with one exception. The exception involves the primary particulate and sulfate contributions at Chino. For the other eleven locations and other origin categories, the origin contribution will be changed (rolled-back) according to total emissions in the Four-County Sub-Area. However, for non-background primary particulates and sulfate at Chino, an allowance will be made for localized emissions.

As explained in Support Document #3, the Chino station appears to experience a particularly strong influence from a localized source. This source, evidently the Kaiser Steel-Edison Electric complex, leads to atypically high primary particulate and sulfate levels at Chino. Estimates of the contributions from the localized source are presented in Table 2-19. The model will be applied in a special way to Chino by rolling back the localized origin contributions (column III in Table 2-19) according to emissions from the localized source and by rolling back the remainder (column II in Table 2-19) according to total emissions in the Four-County Sub-Area.

Arithemetic Means vs. Geometric Means

As explained previously, this study will examine strategies for attaining the annual national standards for particulates. These standards are expressed as annual geometric means (AGM'S), (See Table 2-4). A problem arises since the air quality-emission level model has been formulated in terms of annual arithemetic means, (AAM'S),* A method is needed to reconcile the outputs of the model, (AAM'S), with the form of the air quality standards, (AGM'S).

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* The aerosol origin characterization used arithemetic means in order to present overall linearity.

TABLE 2-19

BREAKDOWN OF PRIMARY PARTICULATE AND SULFATE CONTRIBUTIONS AT CHINO

	COLUMN I Total 1972 non-background level* ($\mu g/m^3$)	COLUMN II Typical Value for similar stations not strongly influenced by the localized source* ($\mu g/m^3$)	COLUMN III Contribution from the localized source (II Minus I) ($\mu g/m^3$)
Primary Suspended Particulates	89	30	59
Sulfates	18	9	9

* See Table 2-17.

Support Document #3 examined this problem through an analysis of the geometric standard deviations associated with particulate concentration distributions. For the purposes of this study, it wad decided to replace the AGM standards by equivalent target AAM levels. The target AAM's were chosen as 80 $\mu g/m^3$ for the primary annual standard and 65 $\mu g/m^3$ for the secondary annual standard. These target arithemtic mean levels are "conservative" in the sense that achieving the target AAM levels will likely result in air quality slightly better than the federal AGM standards.

Air Quality Forecasts for the Baseline Emission Projections

Tables 2-10 and 2-11 summarized the emission projections for primary particulates, SO_2, NOx, and RHC from 1972 through 1980. Projections were given for two scenarios: (1) "Present Controls", (controls presently scheduled to go into effect by the local APCD's and the California ARB plus the federal new car control program), and (2) "EPA Oxidant Plan", (the present controls plus the controls called for in the EPA-promulgated plan for oxidant in the Los Angeles Region). These projected emission levels for the Four-County Area have been transformed into forecasted air quality levels using the air quality model outlined above.* Air quality projections are given for eight locations in Figure 2-26.

---

* As noted above, the model is applied to Chino in a specialized way. The projected primary particulate and SO_2 levels for the local Chino source (assuming no further controls) are as follows:

	(Kaiser/Edison Complex) Emissions as % of 1972 level 1977	 1980
Primary Particulates	150%	147%
SO_2	166%	163%

The details on these results are presented in Appendix A of Support Document #3.

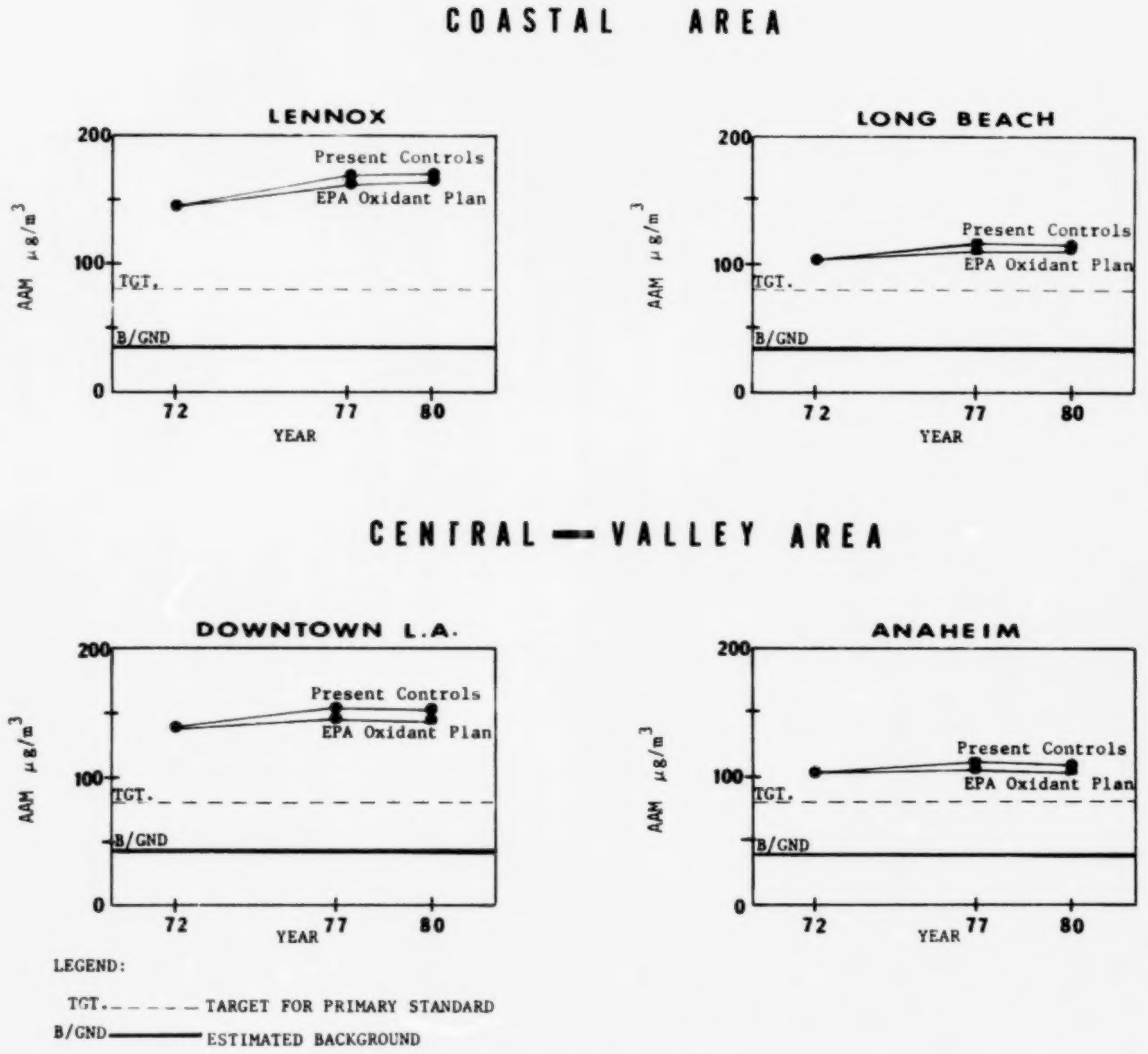


Figure 2-26. Suspended Particulate Air Quality Forecasts for the Baseline Emission Projections, (Present Controls and EPA Oxidant Plan)

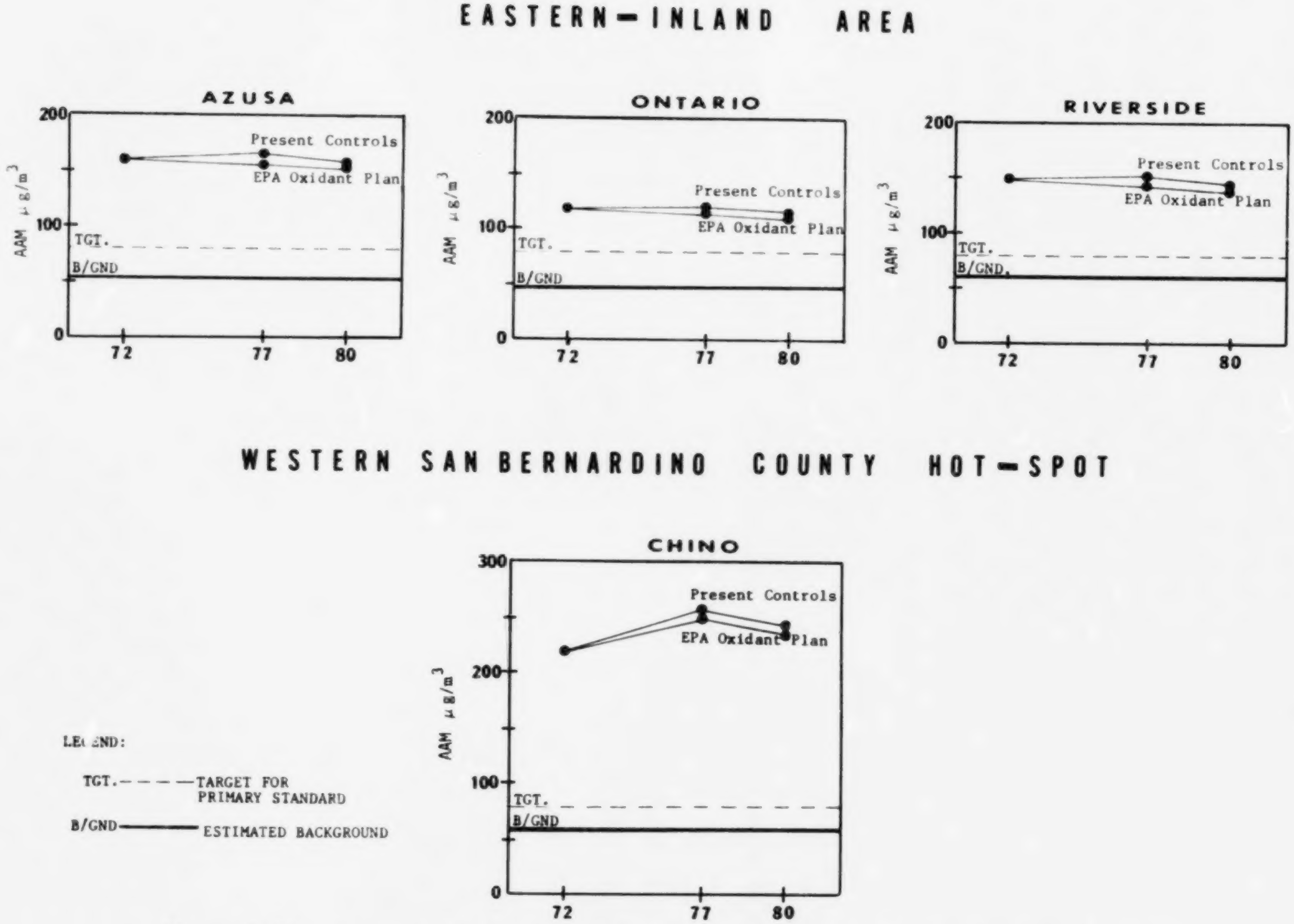


Figure 2-26. Suspended Particulate Air Quality Forecasts for the Baseline Emission Projections, (Present Controls and EPA Oxident Plan) (Continued)

It is apparent that the projected increases in primary particulate, SO_2, and NO_x emissions will lead to a deterioration of suspended particulate air quality at most locations. Reductions in secondary organics (due to decreases in RHC emissions) are sufficient to keep particulate levels about constant in the eastern-inland area where secondary organics are particularly important. The deterioration of air quality is especially pronounced at Chino; with no further controls, the forecasted increase in primary particulates and SO_2 from the Kaiser Steel/Edison Electric complex will result in considerable worsening of an already severe particulate problem.**

In Chapter 4 of this report, control strategies will be proposed for reducing primary particulate, SO_2, NO_x, and RHC emissions in the Los Angeles Region. The effect of these strategies on air quality will be calculated using the linear model developed in this sections. The goal of Chapter 4 will be to identify strategies for approaching and attaining the national air quality standards for particulates in the Los Angeles Region.

** Actually, some significant emission controls are planned for the Kaiser/Edison complex, [46]. They have not been included in the above projections because the expected emission reductions have not yet been documented. These controls may be similar to the controls proposed later in this report.

3.0 ALTERNATIVE EMISSION CONTROL MEASURES

The development of air pollution control strategies for the improvement of ambient air quality depends on a comprehensive consideration of the various alternative emission control measures which are available for use. This section provides an identification and characterization of various alternative emission control measures which might be utilized in the formulation of an air program to achieve the Ambient Air Quality Standards for particulate matter in the Los Angeles Region. This includes an identification of emission control options for the management of gaseous precursors of secondary particulates, namely sulfur dioxide and nitrogen oxides. The omission here of the consideration of emission controls for reactive hydrocarbon precursors was justified on the basis that the control of this pollutant species has already been the principal subject of extensive investigation in the preparation of the State Air Program Implementation plan.

Section 3.1 of this report includes a brief general characterization of alternative control methods which are available for prevention of primary particulate and gaseous precursor emissions. Section 3.2 contains an analysis of the impact of applying these available control methods to specific major source categories, in terms of control effectiveness, technological practicability, and cost. The information contained in these sections has been extracted and summarized from Support Document #4,[4].

3.1 GENERAL CONTROL METHODS AVAILABLE

This section provides a brief general characterization of alternative control methods which are applicable for prevention of emissions leading to the suspension of particulate matter in the atmosphere. A more detailed description of these controls can be found in Support Document #4,[4]. Section 3.1.1 is a summary of the conventional control devices available to manage emissions of primary particulates. Section 3.1.2 includes an identification of alternative controls now available or in development to prevent emissions of gaseous precursors. Section 3.1.3 deals with simultaneous control of primary particulates and gaseous precursors via alternative fuels, and Section 3.1.4 provides a discussion of emissions control by the route of alternative administrative policies (such as shutdown, relocation, and growth retardation).

3.1.1 Controls for Primary Particulates

Feasible control devices for emissions of primary particulates include mechanical collectors, wet scrubbers, electrostatic precipitators, and filters. The application of these various gas cleaning devices is based on consideration of particulate characteristics in the gas stream, and process, operating, construction, and economic factors. The technology of each of the above controls is well developed, and many equipment manufacturers have provided several generations of reliable control devices to the industry.

The table below provides a summary of the typical collection efficiency of various control devices when used in their conventional applications. Cyclones and settling chambers are often used as precleaners in combination with either electrostatic precipitators or fabric filters. Wet scrubbers can be used separately or as a precleaner. Only the electrostatic precipitator and the fabric filter are capable of removing submicron particles with high efficiency, and these devices are used extensively whenever strict regulations apply.

TYPICAL EFFICIENCY RANGES FOR PARTICULATE
COLLECTION DEVICES USED IN CONVENTIONAL
APPLICATIONS

Unit	Efficiency, Percent
settling chambers	20 - 60
large diameter cyclones	30 - 65
small diameter cyclones	70 - 90
wet scrubbers	70 - 99
electrostatic precipitators	75 - 99.5
fabric filters	80 - 99.5

Source: Reference [47].

The cost of preventing emissions of particulates to the atmosphere is related to the collection efficiency of the control equipment. Table 3-1 provides a brief summary of capital costs for the various types of control devices used to collect particulates. The two most efficient control methods, (electrostatic precipitator and the fabric filter) appear to be cost competitive for management of moderate gas flow rates. However, for larger emission control systems, the electrostatic precipitator demonstrates a significant cost advantage.

TABLE 3-1. INSTALLED COSTS OF CONTROL EQUIPMENT

	Approximate Installed Cost, in Thousands of Dollars. Gas Flow Rates (1000 Actual Cubic Feet per Minute)						
Collector Type	2	5	10	15	100	300	500
Gravity	0.5	1.2	2.6	15	28	-	-
Mechanical	-	-	4	13	23	80	-
Wet	-	7.5	10	30	55	150	-
High-voltage electrostatic precipitator	-	-	-	85	120	265	415
Low-voltage electrostatic precipitator	-	13	24	105	200	-	-
Fabric filter:							
High temperature (550°F.)	-	-	30	88	155	430	720
Medium Temperature (250°F.)	-	-	15	45	82	225	375
Afterburner, direct flame	8.2	12	18	-	-	-	-
catalytic	16	20	29	-	-	-	-

Source: Reference [47].

The following sections provice a brief discussion of each of the standard gas cleaning devices in terms of their operating characteristics and applications.

Mechanical Collectors

Mechanical collectors include settling chambers and cyclones. The settling chamber is the simplest particulate collector, typically consisting of a baffle chamber in which the velocity of the polluted gas is diminished to a level where particles settle out by gravity. Mechanical collectors are effective in removing relatively large particles. They are usually employed as pre-cleaners to remove large particles (greater than 43 microns) before the gas is treated by other more efficient removal equipment.

The cyclone provides a configuration in which the polluted gas is introduced tangentially into a conically shaped vessel that directs it along a spiral path. Centrifugal forces push particulates of the gas stream toward the wall, where they fall by gravity to the bottom of the device. The inner flow of clean air travels up the center of the cyclone and exits out the top.

Cyclones are widely employed in various industrial applications for both pre-treatment or secondary gas cleaning operations. They are used in fertilizer plants, petroleum refineries, mineral processing, metallurgical operations, chemical processing, metals manufacturing, and so forth.

Wet Scrubbers

Wet collectors are devices which employ liquids to remove particles by: 1) increasing the effective size of the particles to enable efficient collection, and 2) trapping and washing away particles in a liquid film. This particulate-liquid interface occurs through the physical processes of interception, gravitation, impingement, diffusion, electrostatic forces, and thermal gradients.

There are principally two classes of wet scrubbers: the low energy type and the high energy type. The low energy type includes

- Open spray towers.
- Packed towers, in which the polluted gas and liquid pass cross flow through a contact bed.

- Wet cyclone, in which water spray and centrifugal forces work in combination to collect particles.
- Flooded bed scrubbers, in which baffle grids cooperate in aiding contact between particles and water spray.
- Orifice type, in which the polluted gas is directed through an orifice restricted by liquid spray.
- Wet dynamic, which consists of a liquid spray in an impeller cyclone.

The high energy wet collectors are commonly known as Venturi scrubbers. In a Venturi scrubber high collection efficiency is obtained by high velocity impingement of the gas particles with the scrubbing liquid spray in the throat of a Venturi. The liquid is injected into the throat of the Venturi where the velocity of the gases causes the disintegration of the liquid to fine droplets. This disintegration enhances the probability of contact with particulates of the gas stream.

The collection efficiency of scrubbers varies with the power input. Table 3-2 summarizes the efficiency of the various types of scrubbers discussed above.

Electrostatic Precipitators

The electrostatic precipitator is most frequently used to process large volumes of gas (50,000 to 2,000,000 CFM) at large industrial installations. In many applications, the precipitator is the only proven high-efficiency (up to 99.9% removal) particulate control device available today. They are used extensively to process polluted effluent gases from smelters, furnaces, petroleum refineries, acid plants, boilers, and other process operations.

TABLE 3-2. SCRUBBER CAPABILITIES

Type of Scrubber	Usual Range of Particle Sizes, Microns	Normal Draft Loss, In Water	Maximum Efficiency %
Open spray tower	10.0	3/4-2	85
Packed tower	10.0	1-6	85
Wet centrifugal	2.5	2-6	95
Flooded bed	2.5	2-8	95
Orifice	2.5	To 6	95
Wet cynamic	2.0	None	98
Venturi	0.5	6-80	99+
Flooded disk	0.5	6-70	99+

Source: Reference [48].

The electrostatic precipitator collects suspended particulates by directing the polluted gas through an electrical field. The field is established between an electrode maintained at high voltage and a grounded collection surface. Particles passing through the field become charged immediately and are attracted to the grounded collecting surface. The particulate matter is dislodged from the collecting surface by mechanical means such as vibrating with rappers or by flushing with liquids.

The electrostatic precipitator is a versatile approach to particulate collection in that it may handle a variety of applications at very high efficiencies. It is used to collect particles in the submicron size range, and is capable of operation at temperatures exceeding 1000°F, and at pressures up to 150 psi. A distinct advantage of the configuration of either type of precipitator is the low pressure drop associated with the gas flow path, permitting immense volumes of gas to be handled with relatively low level of power required. Because the design of the precipitator requires considerable experience for a given application, the industry relies heavily on the air pollution control device manufacturer to develop equipment specifications and provide guarantees of performance.

Filter Collectors

Collecting devices based on fabric filtration are among the oldest means of removing material from gas streams. In fabric filtration, the particulate matter is removed from the gas stream by impinging on or adhering to fibers of the fabric. The physical mechanism for particle collection includes interception, inertial impaction, diffusion, electrostatic attraction, sieving, and gravitational settling. Fabric filtration is an effective device for removal of particles as small as .5 micron and will remove a substantial quantity of particles as small as .01 micron.

Fabric filtration is typically accomplished by directing the pollutant-bearing gas through flat or tubular fabric bags hanging in an enclosure called a baghouse. The particulate material is retained on the upstream side of the fabric while the cleaned air which passes through the fabric is discharged to the atmosphere. The collected material is removed from the bags by mechanical means, such as manual shaking or air shaking.

The selection of the fabric is probably the most critical aspect of the equipment design. Determining the resistance of the filter to gas flow for the clean fabric, and for dust laden fabric are important prerequisites to intake and exhaust system design. Optimal air flow ratio through the fabric is another important consideration. Experience in numerous applications (cement kilns, foundary cupolas, furnaces, grain operations) have provided the baghouse device manufacturers with detailed performance characteristics of the many different bag fabrics and baghouse systems. These data allow the manufacturer to guarantee high efficiency baghouse installations in varied applications.

3.1.2 Controls for Gaseous Precursors

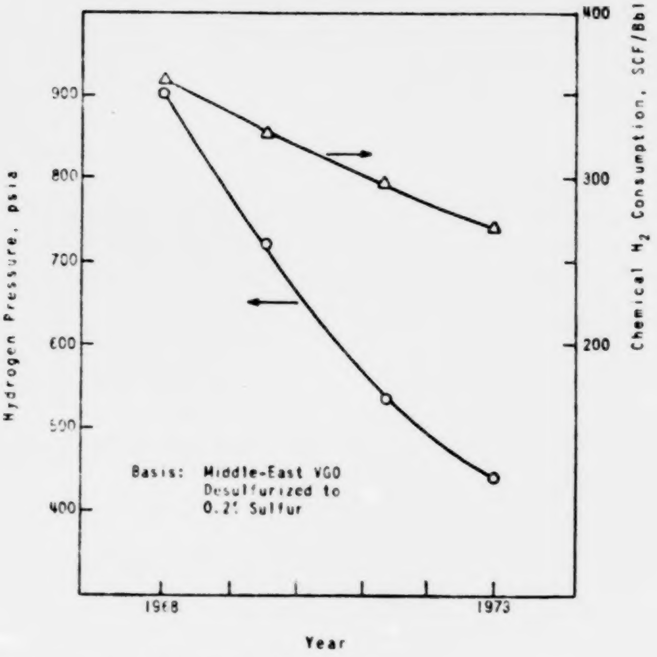
Gaseous emissions which play a major role as precursors to particulate formation in the atmosphere are NO_x, SO_2, and hydrocarbons. The following sections provide a brief description of the most promising control methods which are applicable to prevention of SO_2, NO_x, and hydrocarbon emissions.

Desulfurization of Petroleum Products

The trend toward the processing of higher sulfur crude oils coincides with the trend of increasingly stringent emission regulations, which are causing restrictions on the sulfur content of refinery products, as well as on the sulfur level of refinery process emissions. These concurrent trends obviate the need to develop additional sulfur removal facilities in U. S. oil refineries.

Desulfurization of the heavier fractions of crudes (from diesel/No. 2 oil to heavy fuel oils) has not been extensively practiced in the U. S. to date. The production of low sulfur products in the heavier fractions of the crude will require catalytic hydrodesulfurization of the heavy distillates and residuum fuel oil stocks. Extensive processing of this type has been employed in foreign countries, especially Japan. In many cases, improved technology in desulfurization of the heavy distillates to produce very low sulfur blend stocks has deferred the need for facilities to desulfurize the residuum portion of the barrel. The residuum portion is blended with the low sulfur blend stocks to obtain low sulfur fuel oils meeting the standards

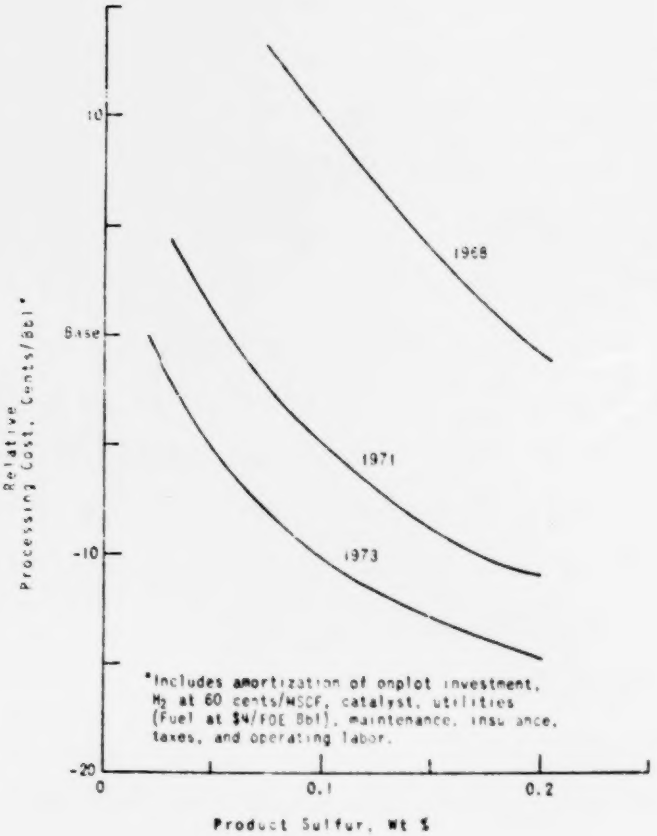
While many of the initial desulfurization facilities were designed to reduce sulfur levels to prevailing standards, the technology is now available for desulfurization of vacuum gas oils to levels of a few parts per million sulfur. Chevron claims their VGO Isomax Process, which was first operated in Japan five years ago, is capable of sulfur levels as low as 100-200 ppm with only moderate increases in operating severity (high pressure and temperature) over the conditions which produce sulfur contents of .1 - .2 percent sulfur. Figure 3-1 illustrates progress made in the last five years in terms of the operating pressure required to remove 92% of the sulfur from a Middle East vacuum gas oil.



Source: Reference [49].

Figure 3-1. Continued Improvement in VGO Isomax Process

Technical improvements in desulfurization processes have had dramatic effects on processing costs. Figure 3-2 summarizes the trend to lower costs. At current levels of technology, the Chevron Isomax Process can produce .05% sulfur fuel oil blend stock at less cost than required to produce .2% sulfur fuel oil blend a few years ago.



Source: Reference [49].

Figure 3-2. Cost to Desulfurize Arabian Heavy Crude Oil with VGO Isomax

Typically the VGO Isomax Process has not been utilized to produce very low sulfur content products as the standards do not generally require this degree of operation. In fact, because of the ability of the VGO isomax to process low sulfur fuels far below standards, a VRDS Isomax process has been designed to complement the VGO Isomax process by providing for moderate sulfur content fuels which may be blended with VGO Isomax fuels to reach the higher limits of the sulfur content standards. The VRDS Isomax is a moderate pressure, vacuum residuum desulfurization process which will process a wide variety of high sulfur content residual to produce sulfur products in the range of .5 to 1% sulfur content. Blending of VRDS Isomax products with the low sulfur products of the Isomax unit provides the most economic route for manufacturing low sulfur fuel oils meeting the current sulfur content standards.

The VGO Isomax is an efficient tool to remove sulfur from the vacuum gas oils of the fuel oil barrel. However it is becoming evident that low sulfur processing of both vacuum residuum as well as the vacuum gas oil will be needed to meet lower sulfur fuel oil requirements. There are several processing schemes being studied as possible routes to very low sulfur fuels (such as .05 to 1% sulfur). Chevron Research has identified two of the most feasible methods as:

1) Solvent-deasphalting and gasification of the by-product high sulfur SDA tar, and
2) VRDS Isomax followed by delayed coking of the VRDS bottoms product.

In the first of the two methods, the vacuum residuum is solvent deasphalted and then combined with the vacuum gas oil for desulfurization in the VGO Isomax process to give a 93% yield on low sulfur fuel oil. Gasification facilities are included to convert high sulfur by-product tar to a useful high BTU content synthetic field gas.

The solvent-deasphalted oil is more difficult to desulfurize in the VGO Isomax Unit than the straight run vacuum gas oil above. However the blend of the two oils does not require appreciably different processing conditions than those which are used in existing commercial VGO Isomax Units. The VGO Isomax Plus solvent-deasphalting process is well established and has been operative at the Standard Richmond Refinery over the past eight years. Experience has shown that high yields of low sulfur fuel oils can be obtained.

In the second of the two methods above, vacuum residuum is processed in a VRDS Isomax Unit and the higher boiling products are sent to a delayed coker. The lower boiling fractions (975°F) are combined with the vacuum gas oil for desulfurization in the VGO Isomax to result in the desired low sulfur fuel oil. This process provides a 93% yield of fuel oil from high sulfur Arabian residuum. Metallurgical quality coke is removed as a useful by-product from the delayer coker.

Chevron Research has demonstrated the two processed above with pilot plant studies using difficult high sulfur feed stocks such as Arabian Heavy. Results of test runs show that refineries can process high sulfur crude while maintaining product quality and meeting environmental standards. Both processes lend to stepwise construction at the refinery. The VRDS Isomax and the VGO Isomax can be integrated into existing refineries with delayed coking and catalytic cracking facilities.

Cost comparisons reveal that initial capital investment is similar for the two low sulfur processing approaches. In terms of processing costs, the Isomax VGO/VRDS plus delayed coker method is superior by about 36 cents/barrel of low sulfur product over the Isomax VGO/Solvent-Deasphalting plus gasification process plan. Process costs depend somewhat on the market demand for the by-products of the two approaches, which tend to fluctuate greatly. Initial investment and manufacturing costs for the two desulfurization schemes are outlined in Support Document #4, [4].

SO_2 Removal Technology

Commercial methods for desulfurization of tail gas from sulfur plants, stack gases, and other effluent gas streams amount to some 20 techniques which are representative of more than 50 identifiable processes. These SO_2 removal systems are in various phases of development and the number of actual applications have been limited to date. Because of performance uncertainties associated with the infant SO_2 control systems, industry is not rushing to purchase these expensive systems, despite the approaching clean air deadlines.

Virtually every desulfurization control process has its own chemical, engineering, economic, and operating peculiarities. Some processes are particularly suited to meet one set of plant effluent conditions, while another SO_2 removal process may be best adapted to an entirely different set of plant parameters. Since there are probably as many different plant effluent-gas-stream types as there are plants emitting gases, the combinations of effluent stream and desulfurization techniques are practically unlimited.

In the long term, radical new technologies may lead to entirely different process systems which are compatible with the ambient air quality goals. However until such new technology is available, "add on" control systems are a more likely candidate method for achieving the imminent and stringent future SO_2 emission regulations. Table 3-3 provides a description of 14 of the principle techniques now being adapted or considered for SO_2 removal in different process effluent streams. The choice of technique in any application depends on the nature of the gas stream being treated and a variety of engineering and economic factors related to each situation.

Sulfur can exist in a large number of oxidation states. The common oxidation states of sulfur found in process effluent gas streams are those typified by H_2S (-2), elemental sulfur (zero), SO_2 (+4) and SO_3 (+6). The reduction-oxidation interconversion of sulfur between the oxidation states -2, 0, +4, and +6 is an essential feature of current and proposed desulfurization processes. In each of the processes the objective is to produce a sulfur product which may be removed mechanically from the system. This corresponds to an oxidation state of either zero (elemental sulfur) or +6 (sulfuric acid and sulfates). To convert the various oxidation states of sulfur existing in an effluent gas, a wide range of oxidizing and reducing agents is used. The conversion route may involve an indirect pathway, such as +4 to -2 to zero as in the Beavon Process, +4 to +6 in the Mitsubishi Process, and other variations as shown in Table 3-3.

Characterization of the effluent stream is the first step in selection of an appropriate desulfurization process. Effluents from combustion sources such as power generating stations are rich in SO_2 with little or no H_2S content due to prior oxidation incineration. These conditions would tend to encourage the use of processes that handle SO_2

TABLE 3-3. PROCESS FOR DESULFURIZATION OF EFFLUENT GAS STREAMS PROCESSED PRINCIPALLY IN THE GAS PHASE

	Process (Developer)	Comments	Process Chemistry
	YIELDING SULFURIC ACID OR SULFATE (S = + 6)		
1.	Dry limestone (TVA)	Simultaneous reaction of SO_2 with lime and air oxidantion of resulting sulfite to sulfate. End product slag requires suitable disposal. Swedish Bahco Process uses hydrated lime slurry. Lignite ash also used as absorber (Carl Still, W. Germany).	$CaCO_3 \longrightarrow CaO \xrightarrow{SO_2,\ SO_3,\ AIR} CaSO_4$ $+\ CO_2$ (TO ATMOSPHERE)
2.	Manganese dioxide (Mitsubishi)	Initial concentration and oxidation of SO_2 to metal sulfate with air regeneration of MnO_2 oxygen carrier and ammonium sulfate (fertilizer) production.	$SO_2 \xrightarrow[MnO_2]{} MnSO_4 \xrightarrow[AIR]{NH_4OH} (NH_4)_2\ SO_4 + H_2O$ REGENERATION
3.	Active magnesia (Showa Hatsuden) (Chemico)	Essentially a concentration process using MgO as a "collector" followed by regeneration of concentrated SO_2 stream for sulfuric acid plant feed.	$SO_2 \xrightarrow[MGD]{200^\circ\text{-}300^\circ F} MGSO_3 \xrightarrow{1400^\circ F} 15\%\ SO_2$ GAS REGENERATION ↓ CONTACT PROCESS H_2SO_4
4.	Modified contact	Essential Contact Process yield acid (Monsanto) or ammonium sulfate (Tokyo) but accepts hot dilute SO_2 gas stream rather than high SO_2 acid plant feed. (See also Topsoe Process)	$AIR + SO_2 \xrightarrow[V_2O_5]{900^\circ F} SO_3 \xrightarrow[H_2O]{} H_2SO_4$ $SO_3 \xrightarrow[2NH_4OH]{} (NH_4)SO_4 + H_2O$
5.	Activated carbon	All methods depend on absorptive powers of various forms active carbon to first concentrate and then catalyze exidation SO_2 to SO_3 for acid or sulfate production. Fluidized, fixed and plugged flow beds variously employed	$SO_2 \xrightarrow[ACTIVE\ CARBON]{AIR,\ H_2O} H_2SO_4$

TABLE 3-3. PROCESS FOR DESULFURIZATION OF EFFLUENT GAS STREAMS (CONTINUED)

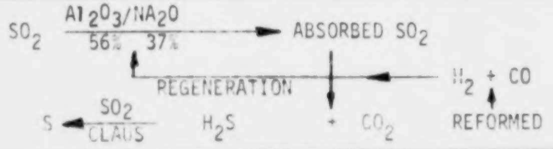
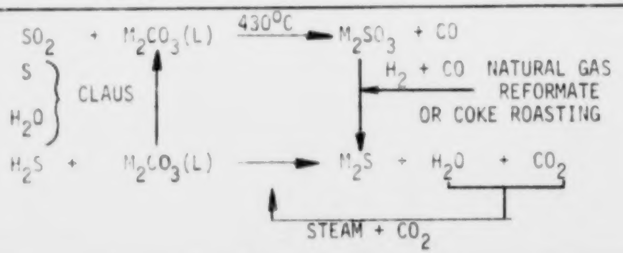
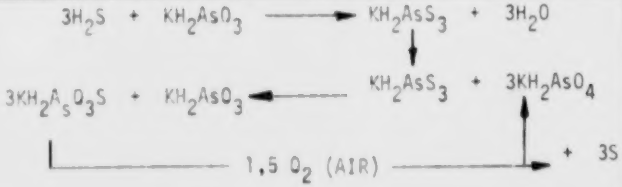
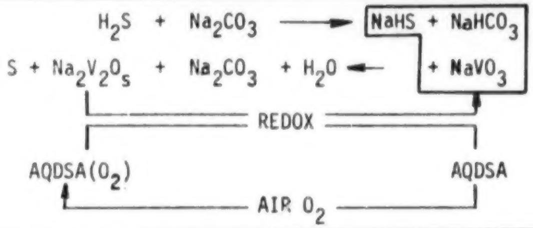
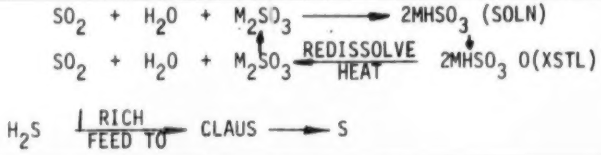
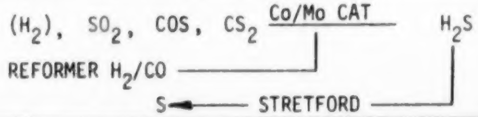
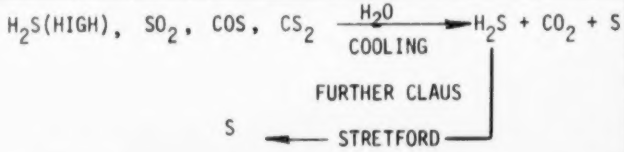
Process (Developer)	Comments	Process Chemistry
YIELDING SULFUR (S = ZERO)		
6. Sulfreen (SNPA-Lurgi)	Catalytic use of active carbon for high efficiency Claus redox reaction to yield sulfur rather than oxidantion of SO_2 to $SO_4^=$. Requires both H_2S and SO_2 in stream.	$H_2S + SO_2 \xrightarrow[\text{ACTIVE CARBON}]{} H_2O + S$
7. Alkalized alumina (U.S.Bur.of Mines discont.) U.K. Cent. Elec.Board	Concentration of dilute SO_2 stream on Alk/alumina and in situ catalytic reduction to H_2S using reformer Hb, HS then to Claus with regenerated SO_2.	 SO_2 Al_2O_3/NA_2O 56% 37% ABSORBED SO_2 REGENERATION H_2 + CO REFORMED S SO_2 CLAUS H_2S + CO_2
Processes With At Least One Principal Solution Stage		
8. Molten salt (Atomics,Intn'l) (Garrett, Res.& Dev.)	Dilute SO_2 concentrated by absorption in molten salt as sulfite and reduced by H_2 (Atomics) or coke roasting (Garrett) to sulfide and hence H_2S. Both processes feed Claus.	 SO_2 + $M_2CO_3(L)$ 430°C M_2SO_3 + CO S H_2O CLAUS H_2 + CO NATURAL GAS REFORMATE OR COKE ROASTING H_2S + $M_2CO_3(L)$ M_2S + H_2O + CO_2 STEAM + CO_2
9. Solution Claus (Inst. Francais du Petrole)	Essentially Claus redox in solution with or without added catalyst. High boiling solvents preferred to accept hot gases without extensive cooling.	$H_2S + SO_2 \xrightarrow[\text{POLYGLYCOL SOLVENT (M.W. ~400)}]{\text{METAL SALT CATALYST}} S + H_2O$
10. Giammarco-Vetrocoke	Solution oxidation of H_2S absorbed as thioarsenite with arsenate/arsenite air regeneratable redox couple as oxygen carrier. Several similar systems involving inorganic redox couples (thylox, manchester, lacykeller exist.	 $3H_2S$ + KH_2AsO_3 KH_2AsS_3 + $3H_2O$ KH_2AsS_3 + $3KH_2AsO_4$ $3KH_2A_sO_3S$ + KH_2AsO_3 1,5 O_2 (AIR) + 3S

TABLE 3-3. PROCESS FOR DESULFURIZATION OF EFFLUENT GAS STREAMS (CONTINUED)

	Process (Developer)	Comments	Process Chemistry
	YIELDING SULFUR (S = ZERO) (Continued)		
11.	Stretford U.K. North W. Gas Board)	Solution oxidation of H_2S absorbed as Bisulfide by two stage redox couple involving vanadate and anthraquinone disulfonic acid as oxygen carriers. Takahax uses napthaquinone.	 $H_2S + Na_2CO_3 \rightarrow NaHS + NaHCO_3 + NaVO_3$ $S + Na_2V_2O_5 + Na_2CO_3 + H_2O$ REDOX AQDSA(O_2) AQDSA AIR O_2
12.	Wellman-Lord	A solution method for concentrating dilute SO_2 steam to rich feed for Claus by bisulfite formation, crystallization and thermal regeneration. No reduction or oxidation in solution step.	 $SO_2 + H_2O + M_2SO_3 \rightarrow 2MHSO_3$ (SOLN) $SO_2 + H_2O + M_2SO_3$ REDISSOLVE HEAT $2MHSO_3$ 0(XSTL) H_2S RICH FEED TO CLAUS S
13.	Beavon (Parsons Co.)	Preliminary gas phase catalytic hydrogenation all sulfur compounds to H_2S for feed to Stretford. In particular COS and CS_2 reduced.	 (H_2), SO_2, COS, CS_2 Co/Mo CAT H_2S REFORMER H_2/CO S STRETFORD
14.	Cleanair (Pritchard) (IGS)	H_2S rich tail gas water cooled to continue Claus and hydrolyze COS and CS_2; final H_2S to Stretford.	 H_2S(HIGH), SO_2, COS, CS_2 H_2O COOLING $H_2S + CO_2 + S$ FURTHER CLAUS S STRETFORD

Source: Reference [50].

directly and alone. In processes where effluents consist principally of H_2S, such as from oil refinery sour gas processing, those processes designed to treat H_2S alone or both H_2S and SO_2 together may be preferred. Of course the H_2S may be incinerated to SO_2 alone, but this leads to dilution of the effluent and complicates the control process by introducing larger processing volume requirements.

- End Products of Desulfurization Systems:

  All desulfurization processes yield an end product. In some of the processes the product is marketable. Sulfur is the end product in many of the cleanup processes (particularly those applied to sulfur recovery tail gas at oil refineries), and finds wide use as a base chemical. Its marketability fluctuates, and its low dollar-per-ton cost does not begin to enable the cleanup system to pay for itself. However because of its marketability and relative ease of handling, sulfur as an end product may be disposed of conveniently.

  The disposal of sulfuric acid as an end product is complicated by storage problems. Large tonnage storage or long distance hauling is not feasible. Selection of desulfurization cleanup systems yielding sulfuric acid as an end product depends on the presence of a consumer near the process.

  Disposal of ammonium sulfate (the end product in processes such as the ammoniacal solution and manganese dioxide technique) may be costly when moisture protection during storage is required. It can then find immediate use as a fertilizer.

Calcium sulfate, an end product of the dry-limestone process, is a waste requiring land fill disposal.

Water wastes are a disposal problem with all of the large-volume aqueous solution processes. Large volumes of contaminated water must be repurified before recycling or discharging as effluent.

The Wellman Lord cleanup process yields a sodium sulfate which is nonregenerable. Its handling does not pose a problem, but the current market for this process is limited.

- Process Efficiency:

  Performance data for the various desulfurization processes is rather limited, except as each of the processes relates to particular applications now prevalent in the field. In this respect a number of the cleanup processes have proven suitable for SO_2 removal down to concentrations of less than 500 ppm. Initially, desulfurization processes were applied successfully to the tail gas of Claus units at oil refineries. Several units have been operating successfully at various refineries for the past few years. SO_2 cleanup processes have also been installed in Los Angeles, reducing emissions from refinery tail gas to less than 500 ppm as required by new regulations imposed by the APCD. Among those processes capable of reducing SO_2 levels well below 500 ppm in effluent gas streams are the Vetrocoke, Stretford, and Wellman-Lord process. These processes have operated in various tail-gas applications to reduce SO_2 concentrations to less than 200 ppm.

Motivated by imminent new SO_2 emission standards targeted for the electric utilities, several power plants have now been equipped with desulfurization systems which are providing continuous operation at 90% plus SO_2 removal rates. Table 3-4 provides a summary of nine different cleanup processes now under test at various utilities. In Los Angeles, APCD SO_2 emission regulations are met by the electric utilities burning low sulfur fuels, stack emissions are kept under the permissible 2000 ppm SO_2 emission level (Rule 53, Sulfur Compounds Concentration). This control procedure permits relatively low sulfur emissions to be achieved without the need of costly add-on desulfurization systems. However, unless desulfurization of fuels is extended to lower limits, the sulfur removal effected by this strategy may not be satisfactory to meet the moving clean air targets. Add-on desulfurization equipment may then become a candidate control measure for power utilities located in the Four-County Area.

TABLE 3-4. SO_2 REMOVAL PROCESSES CURRENTLY IN TEST

Process	Approx. Test Unit Size, Mw	Developer	Utility
Lime scrubbing (boiler injection)	120	Combustion Engineering	Kansas City Power & Light
Lime scrubbing (scrubber introduction)	120	Chemico	Mitsui Aluminum (Japan)
Limestone scrubbing	117	Babcock & Wilcox	Kansas City Power & Light
Magnesia scrubbing	150	Chemico-Basic	Boston Edison
Catalytic oxidation	100	Monsanto	Illinois Power
Sodium salt scrubbing (thermal regeneration)	125	Wellman-Power Gas	Northern Indiana Public Service
Sodium salt scrubbing (throwaway)	125	Combustion Equipment Associates	Nevada Power
Manganese oxide absorption	110	Mitsubishi	Chubu Electric Power (Japan)
Carbon adsorption	150	Hitachi	Tokyo Electric Power (Japan)

Source: Reference [51].

- Cost:

  Under the new federal regulations, electric utilities are the main target for SO_2 and control systems. The Sulfur Oxide Control Technology Assessment Panel has estimated that the cost of SO_2 stack cleaning for power utilities could increase consumer cost for electricity by 17%. Several utilities have affirmed that SO_2 cleanup technology will increase consumer rates by 20%. The Louisville Gas and Electric Company has stated the cost of its announced SO_2 compliance program for its eight existing units will amount to a rate increase of 30%. Some examples of the capital cost of retrofitting SO_2 cleanup technology in existing power generating plants are shown below:

Size of Plant (MW)	Initial Capital	% per KW	Developer & Utility
800	150	60	Penn Power, Bruce Manifield Station (2 units)
550	42	80	TVA, Widows Creek
65	3.1	50	Louisville Gas & Electric
1650	100	60	Louisville Gas & Electric (8 units)

Although numerous cost estimates have been made for cleaning stack gases, most of the published information is not definitive. It is difficult to evaluate and compare the cost of cleanup processes when there are still many problems to be identified during development. This situation will be remedied as current projects are completed and more operating data has been obtained. In addition, costs will vary widely depending on factors such as plant size and location, cost of raw materials, difficulty of product disposal, and whether the installation is new or retrofit. The present indication is that for power plants investment can be as high as $80/KW with an annual operating cost as high as $2.5/KW.

The costing of desulfurization cleanup systems used to control emissions from the tail gas of Claus sulfur recovery plants involves less guess work than other applications. SO_2 removal processes have operated continuously with high efficiency at several sulfur recovery plants for the past few years. A high efficiency cleanup system for a typical Claus unit processing 1000 tons/day of sulfur with a tail gas SO_2 concentration of 10,000 ppm would incur a capital cost of $3.5 million.

The problem of high cost for stack desulfurization is compounded by the limited availability of the SO_2 cleanup systems. The Sulfur Oxide Control Technology Assessment Panel has stated that processes may not be readily available for the next few years. Currently there are several scheduled process installations, and if projected emission control standards are implemented in the next few years, commercial demand for the cleanup systems will far exceed the industry's limited manufacturing capacity.

3.1.3 Alternative Fuels - A Control for Particulates, SO_2 and NO_x

Today's energy needs are served primarily by direct use of fossil fuels. The disappearing reserves of these fuels for low cost energy, and the concern over long-term energy supply, has recently given rise to investigation of alternative energy systems by various energy planning agencies. Synthetic fuels from non-fossil sources are now being advocated as the most suitable alternative for supplying the long term needs for gaseous and liquid fuels. However, in the near term, until technology is more advanced, even synthetic fuels will require fossil sources such as coal and oil shale.

A conversion to synthetic fuel systems would have dramatic impact on air quality problems. Consumption of synthetic fuels in these systems results in very little air pollution, and would eliminate the immense effort now targeted for control of air pollutant emissions from fossil energy use.

Among the comprehensive studies of potential fuels, methanol is described as the most desirable of the alternatives in many ways. Hydrogen, which has been suggested as a universal, nonpolluting fuel, is expensive, difficult to store and transport, unadaptable to current fuel-using equipment, and hazardous; the use of methanol does not pose these problems.

Methyl-fuel can serve as a substitute in many current fuel systems. In full scale boiler combustion tests, methyl-fuel has proven itself an effective air pollution control measure. The burning of methyl-fuel produced virtually no unburned hudrocarbons, SO_2, or particulate emissions, and NO_x emissions were reduced below that produced under firing of natural gas. Methyl-fuel is especially attractive as a fuel substitute for motor vehicles, and can be utilized as an additive to current fuel stocks without special adaption. Its research octane blend value of 130 makes it a possible octane booster substitute, and because it has no lead or sulfur it can be used compatibly with motor vehicles equipped with catalytic exhaust control devices. When methyl-alcohol is used as a complete motor fuel substitute (requiring engine adaption estimated at $100 per vehicle), exhaust emissions are reduced by 80%,[52],[53].

Methanol is produced by reacting synthesis gas (CO, CO_2, and H_2) at various temperatures and pressure in the presence of a catalyst. In the typical commercial production of methanol, the synthesis gas is produced by reacting steam and methane. However the synthesis gas can also be produced from natural gas and carbonaceous materials such as oil shale, coal, and refuse. In the manufacture of methanol the output can be increased by 50% if small amounts of other alcohols can be tolerated in the product. Such a mixture is called "methyl-fuel," and can be produced in larger quantities and lower prices than pure methanol, and has superior properties as a fuel.

In the near term, coal must be utilized to achieve large scale methyl-fuel production. However the desirability of coal for methyl-fuel production depends heavily upon successful coal gasification design. Intensified development is now under way to provide these designs, and some have proven feasible already. These systems are similar to those already built on commercial scale for the U. S. Bureau of Mines and various chemical companies.

- Economics of Methyl-Fuel Production:

  In the past two years, dramatic changes have occurred in the world economic situation, affecting the cost of many types of raw materials. The price of petroleum has increased by a factor of five, and costs are now rising to reflect the increased demand for coal. While the current uncertainties in the marketplace suggest restraint in economic projection, it does appear that the current trend is pricing alternative fuels into competition. The cost of fuel oil to the fuel-burning utility companies is presently $15 per barrel, or $2.46 per million BTU.

One of the principal drawbacks to the immediate use of methyl-fuel as a substitute in fuel combustion equipment is its availability. Currently the projected market for this fuel is limited. In addition, it may be difficult to provide the coal resources needed for expansive manufacturing of methyl-fuel. The nation is currently engaged in a program to increase utilization of coal for generation of electric power, and limited coal availability has already placed uncertainties on that effort. Environmental concern over land abuse by coalmining is a primary constraint to plentiful coal supply. However, an advantage contained in the methyl-fuel production is that it will use "low quality" lignite coal, a cheaper and lower demand coal.

In addition to material supply problems confronting any immediate plan for large scale production of a substitute fuel, there are obvious social and political disruptions inherent in a plan proposing radical manufacturing and consumer conversions. If air quality standards are to be met in the near term through fuel conversion policy, the disruptions are inevitable, and probably, intolerable. However, if environmental standards are promulgated to promote alternative fuels over the long term, the transition would appear to be feasible. The market demand may very well supplant this long term possibility. It has been estimated that by 1975 there will exist a market for 18 methyl-fuel plants by coal gasification. By 1980 the demand will be 28. According to the Vulcan-Cincinnati Company, who has a proprietary hold for the manufacture of methyl-fuel, it would be possible to construct these fuel plants by 1980. By 1990 the market demand is projected at 120 plants,[53].

In the long term, methyl-fuel conversion appears practical. In fact, the apparent far reaching attractiveness of methyl-fuel conversion as a long term approach to air resources management problems would seem to raise serious questions as to the sensibility of current air quality achievement goals predicated on rapid timetables. In the long term, deferment of present short term air quality objectives could have significant impact on the rate of development of far reaching alternatives such as methyl-fuel substitution. More investigation is needed to determine the relationship between these factors.

3.1.4 Non-Technological Control Measures

The total regional emission rate from a certain type of air pollution source can usually be described as a product of three factors:*

$$\begin{pmatrix}\text{Total}\\ \text{Regional}\\ \text{Emission}\\ \text{Rate}\end{pmatrix} = \begin{pmatrix}\text{Number of}\\ \text{Source Units}\\ \text{in Region}\end{pmatrix} \times \begin{pmatrix}\text{Average}\\ \text{Source}\\ \text{Usage}\\ \text{Level}\end{pmatrix} \times \begin{pmatrix}\text{Average}\\ \text{Source}\\ \text{Emission}\\ \text{Factor}\end{pmatrix}$$

The controls considered so far in this chapter have essentially dealt with methods for reducing the last of these three factors. The above controls have consisted of modifications of processes or additions of cleaning devices so as to reduce average source emission factors. As such, they might be called "Technological" controls.

This section will briefly examine "non-technological controls", that is, controls aimed at reducing source numbers or source usage. Source relocation and growth restrictions will be the two methods examined for decreasing source numbers. The discussion of source usage control will emphasize vehicle use reductions, i.e., vehicle miles travelled (VMT) restrictions.

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* For example, regional NO_x emissions from motor vehicles (say in tons/day), equal the number of vehicles times the miles travelled per vehicle per day times NO_x emission per vehicle mile.

It is not unappropriate that non-technological controls are considered last in this chapter. As will be evidenced by the discussions below, there are very great socio-economic costs and implementation problems associated with non-technological controls, especially when they are considered over the short-term, (say 5 to 10 years). It may be difficult to implement strict technological controls for motor vehicles, aircraft, power plants, or industries. However, the resistance to measures such as 50 percent VMT reduction, industry relocations, or a no gravity policy can be much greater. On the short-run, non-technological controls are somewhat a last resort. They sould be considered here, however, since very large reductions in total emission levels will be needed to approach the national air quality standards for particulates in the Los Angeles Region.

Growth Restrictions

Control measures which limit community growth provide an important means of maintaining air quality. These measures may be geared toward discouragement of new growth (disincentive measures) or toward total prohibitions. Alternative measures providing disincentive to growth have been outlined in a recent TRW study on Air Quality Maintenance for the San Diego Area,[54]. The measures include various restrictions on land use such as special residential zoning ordinances, environmental impact reporting, special taxation rates, open space planning, and capital improvements requirements. The severity of the restrictions is established to reflect the degree of growth control needed to maintain air quality levels within standards.

Due to the substantial magnitude of the air pollution problem in the Los Angeles Area, it may be necessary to consider implementation of control measures which would actually prohibit certain types of growth. These prohibitions might be directed at the more significant sources, and could include such restrictions as a limit on motor vehicle registrations, prohibitions on industrial expansion, prohibition of airport expansions, limits on utility service hook-up, etc.

Relocation

Source relocation is potentially a very effective method for reducing total regionwide emission levels. However, unless one is moving significant portions of the human population out of the air basin, (which some may agree is the step that is actually necessary to attain all present air quality standards in Los Angeles), source relocation appears to be most appropriate for large, concentrated sources. It is usually a much more difficult problem to relocate area sources, such as traffic, residence, etc. Accordingly, in this study, relocations will be considered only for concentrated or point sources.

The major candidates for relocation in the Los Angeles area are the international airport, power plants, refineries, and certain large industries. The re-shifting of any of these facilities would invalue a tremendous cost and would be resisted by very strong political forces. It is not within the scope of this study to examine these costs and implementation problems in detail. Rather, this study will just note the amount of relocation that may be necessary to meet the air quality standards. If relocation is actually chosen by control agencies as a viable measure, further study will have to be given to the impact associated with its implementation.

Source Usage

Restriction of source usage rates is potentially a very effective method of reducing emissions. Examples would be limits on power plant operating level, refinery throughout, or motor vehicle travel. Usage limits for large stationary sources would be equivalent to growth control (for slight restrictions) or to partial relocation (for severe restrictions). The following discussion will concentrate on use controls for motor vehicles.

Recent transportation studies have examined the effect of alternative policies for reducing vehicle miles travelled (VMT), [55], [56], [57]. The list of potential measures which have been studied include the following:

- Improvements in bus services
- New rail transit service
- Auto free zones
- Increased parking costs
- Carpool promotion
- Exclusive bus and/or carpool lanes

A study for Los Angeles indicates that each of these measures (when carried out at a reasonable level) would produce only marginal reductions in VMT, (from .1 percent to 5 percent), [55]. A comprehensive program comprised of all these would only be expected to reduce VMT by 10 to 20 percent. In order to produce larger changes in VMT, say on the order of 50 percent, gasoline rationing appears to be the most appropriate step. The reader is referred to references [55], [56], and [57] for a detailed discussion of potential VMT reduction measures and their impacts.

3.2 SUMMARY OF CONTROL ALTERNATIVES FOR EMISSION SOURCES IN THE FOUR COUNTY AREA

This section provides an identification of those alternative control methods of Section 3.1 which may be applied to specific emission source categories in the Four County Area. Tables 3-5, 3-6, 3-7 and 3-8 contain a summary of these control options for the control of particulates, SO_2, NO_x, and reactive hydrocarbons (RHC), respectively. Included in the first three tables is: 1) an assessment of the emission control impact of each of the control methods, in terms of the emission reductions expected from the control in 1977 and 1980, 2) a tabulation of the cost effectiveness of the control measures, and 3) the baseline projected emission inventory for the various source categories when the EPA oxidant plan is implemented. Since no additional controls were examined to be added to the EPA oxidant/RHC control program, Table 3-8 presents a summary of the RHC emission inventory only.

Various air pollution control techniques were identified in the study as candidates to improve the control of emissions from the major source categories. The most significant emission control options identified are: 1) desulfurization of petroleum products to very low sulfur levels, 2) alternative fuels, 3) SO_2 removal processes, 4) motor vehicle particulate traps, 5) fabric filters or baghouses, and 6) electrical precipitators.

The first three control options listed above each represent a relatively new state of the art in emission control technology. Desulfurization of petroleum products to very low sulfur content has been practiced commercially in very few applications. However, the technology has been proven, and it appears to be suitable for the production of very low sulfur fuel oils, and for motor vehicle fuels with sulfur contents below 100 ppm.

TABLE 3-5

ALTERNATIVE CONTROL MEASURES FOR PREVENTION OF PARTICULATE EMISSION IN THE FOUR-COUNTY AREA

PARTICULATE BASELINE EMISSIONS						SOURCE CATEGORY	CONTROL MEASURE	PARTICULATE EMISSION REDUCTIONS (TONS/DAY)				COST EFFECTIVENESS (Cost per Ton of Particulate Emissions Prevented)
TOTAL			SUSPENDED					TOTAL		SUSPENDED		
1972	1977	1980	1972	1977	1980			1977	1980	1977	1980	
3	3	3	3	3	3	Petroleum Industry	1) Improve efficiency of regenerator unit dust control system from 95% to 99% (by upgrade of precipitator).	1.8	1.8	1.8	1.8	$512
							2) Require SO_2 removal equipment for stack control (90% removal) of regenerator unit.	.7	.7	.7	.7	$193
84.9	83.5	86.1	84.7	82.6	85.2	Stationary Fuel Combustion	1) High efficiency electrostatic precipitation on power plant boilers, large non-power plant boilers, and refinery heaters.	64.6	61.7	63.8	60.9	$1520
							2) High efficiency baghouse for application on power plant boilers, large non-power plant boilers, and refinery heaters.	67.9	64.7	67.1	63.9	$1540
							3) Desulfurization of fuel oils to .05% S with new desulfurization technology. To be applied to power plant boilers and large non-power plant boilers.	12	23	11.3	22.3	$14100[a]
							4) Fuel conversion to methyl-fuel in all combustion units which can use fuel oil.		65		64.3	$5730
12.1	12.5	12.8	11.2	11.4	12.0	Minerals Industry	No significant alternative identified	0	0	0	0	-
15.0	26.0	38.1	14.2	25.9	37.0	Aircraft Operations	1) Major combustion chamber redesign in turbine engines.	11.1	16.4	10.4	15.3	$6100[b]
							2) Modification of turbine aircraft ground operations - towing of aircraft to avoid taxi idle emissions.	4.9	7.2	4.7	6.9	$300[c]
							3) 1 and 2 above	13.6	19.6	12.9	18.6	$2930
[illegible].4[d]	71.4[d]	64.2[d]	72.1[d]	63.6[d]	64.2[d]	Motor Vehicles	1) Remove lead in all motor fuels	9.8	7.3	5.1	4.3	$475
							2) Desulfurize motor fuels to 100 ppm sulfur content	15.5	19.0	13.4	17.0	$3050[e]
							3) Equip motor vehicles (without catalytic converters) with particulate traps.	25.0	17.6	21.3	14.6	$1500
							4) Equip all motor vehicles with SO_2 scrubber	46.0	44.3	42.1	41.4	$4630[e]
							5) (2) and (3) above (Desulfurization and particulate traps	40.5	37.4	34.7	31.6	$2280
							6) (2) and (4) above. (Desulfurization and SO_2 scrubber/particulate trap)	48.4	46.3	44.0	43.3	$6300
8.0	8.5	8.7	7.2	7.7	7.9	Organic Solvents	1) Equip all paint spray booths with water wash	6.5	6.7	5.7	5.9	$724
12.3	13.4	14.0	12.3	13.4	14.0	Metallurgical Processes	1) Equip furnaces having uncontrolled particulate emissions with bag house.	7.5	7.9	7.5	7.9	$1242
9.2	9.7	10.1	8.1	8.7	9.2	Chemical Process Industry	No significant alternatives identified	0	0	0	0	-

[a] The cost effectiveness may be misleading since the control measure is proposed primarily for the abatement of SO_2 emissions, not particulates.

[b] The cost of air pollution control benefits are figured for Four-County Area only, and do not reflect the tons of emission reductions due to operation of the controlled aircraft fleet in other areas.

[c] This control measure is proposed for the control of other types of emissions in addition to particulates.

[d] Includes airborne particulates arising from tire wear.

[e] The cost effectiveness figure may be misleading since this measure is proposed as a control for both particulate and SO_2 emissions.

TABLE 3-6

ALTERNATIVE CONTROL MEASURES FOR PREVENTION OF SO_2 EMISSIONS IN FOUR-COUNTY AREA

BASELINE SO_2 EMISSIONS TONS/DAY			SOURCE CATEGORY	CONTROL MEASURE	SO_2 EMISSION REDUCTION TONS/DAY		COST EFFECTIVENESS (Cost per Ton of SO_2 Emission Prevention)
1972	1977	1980			1977	1980	
60	60	60	Petroleum Industry	1) Require SO_2 removal equipment for stack control.	51.4	51.4	$193
				2) Require desulfurization (to .05% S) of all petroleum feed to catalytic cracker.	51.4	51.4	$964
208	374	380	Stationary Fuel Combustion	1) Desulfurize petroleum residuum to obtain fuel oil with sulfur content of .05%. To be applied to power plant boilers and large non-power plant boilers.	168[a]	308	$1040
				2) Equip all combustion equipment stacks with SO_2 removal systems.	336	342	$1540
				3) Fuel conversion to methyl-fuel in all combustion units which can use fuel oil (power plant boilers, iron-power plant boilers, and refinery heaters).	-	379	$1030
				4) (1) above, and SO_2 removal systems on all refinery heaters.	201	342	$1075
1.4	1.7	1.8	Minerals Industry	No significant alternatives identified.	0	0	-
3.4	6.5	9.6	Aircraft Operation	1) Modification of turbine aircraft ground operations. Tow aircraft to avoid taxi emissions.	1.4	2.1	$750[b]
48.9	46.1	47.0	Motor Vehicle	1) Desulfurization of motor fuels to 100 ppm sulfur content.	35.5	35.3	$1680[c]
				2) Equip all motor vehicles with SO_2 scrubber.	43.8	44.6	$4960[c]
-	-	-	Organic Solvents	None required as this source category does not account for significant SO_2 emissions.	-	-	-
13.0	15.0	15.9	Metallurgical Processes	1) Equip all furnace effluent stacks with SO_2 removal systems.	13.5	14.3	$101
97.0	10.0	10.1	Chemical Industry	No significant alternatives identified. (Control of sulfur recovery plants by local agencies has accounted for the substantial reductions between 1972 and 1977.)	-	-	-

a. Due to long lead time requirements for design and construction of desulfurization equipment, it was assumed that only 1/2 of the required desulfurization plants could be available in 1977.

b. This control measure is proposed for the control of other types of emissions in addition to SO_2.

c. The cost effectiveness figure may be misleading since this measure is proposed as a control for both particulate and SO_2 emissions.

TABLE 3-7. ALTERNATIVE CONTROL MEASURES FOR PREVENTION OF NO_x EMISSIONS IN FOUR-COUNTY AREA

BASELINE NO_x EMISSIONS TONS/DAY			SOURCE CATEGORY	CONTROL MEASURE	NO_x EMISSION REDUCTIONS TONS/DAY		COST EFFECTIVENESS (Cost per Ton of NO_x Prevention).
1972	1977	1980			1977	1980	
67.5	67.5	67.5	Petroleum Industry	No significant alternatives identified.	0	0	-
282	672	629	Stationary Fuel Combustion	1) Initiate low excess air firing and flue gas recirculation for small power plant boilers, and large/medium sized non-power plant boilers.	242	227	$588
				2) Low excess air firing for refinery heaters.	26	24	$111
				3) Water injection or exhaust gas recirculation for stationary internal combustion engines.	66	62	$18
				4) Fuel conversion to methyl-fuel in all combustion units which can use fuel oil (power plant boilers, non-power plant boilers, and refinery heaters).	-	328	$1190
18.6	32.2	45.4	Aircraft Operations	1) Water injection	13.9	20.5	$820
				2) Major combustion chamber redesign.	8.1	12.0	$5770
				3) Modification of ground operations. Tow aircraft to avoid taxi emissions.	2.1	3.2	$1100[a]
				4) (1) and (3) above.	14.8	22.8	$890
950	815	665	Motor Vehicles	No significant alternatives were identified in addition to those already scheduled under the local, state, and federal clean air programs.	0	0	-
-	-	-	Organic Solvents				
.5	.6	.5	Metallurgical Processes				
.4	.5	.5	Chemical Industry				

a. This control measure is proposed for the control of other types of emissions in addition to NO_x.

TABLE 3-8. INVENTORY OF HYDROCARBON EMISSIONS UNDER THE EPA OXIDANT IMPLEMENTATION PLAN*, FOUR COUNTY AREA

Source Category	Emissions When Plan is Implemented		
	1972	1977	1980
Petroleum Industry	67.1	17.3	18.2
Stationary Fuel Combustion	--	--	--
Minerals Industry	--	--	--
Aircraft Operations	15.7	26.7	37.1
Motor Vehicles	961	472	325
Organic Solvents	43.0	30.4	30.0
Metallurgical Processes	--	--	--
Chemical Industry	--	--	--
Other	.7	.8	.8
TOTALS	1095	547	410

*The EPA oxidant plan consists of the following control measures:

- Vapor recovery systems for gasoline marketing operations.
- Inspection/maintenance and catalytic converter retrofit for motor vehicles.
- Restrictions on the use of organic solvents and on emissions from organic solvent operations.

Conversion to synthetic, clean-burning fuels is another possible air pollution control option in which new technology must be consolidated into commerical production systems. Various studies have demonstrated the adaptability of current fuel systems to methanol fuel, and confirmed its effectiveness in reducing polluting emissions from fuel burning operations. Construction of several large methanol producing plants is now being considered as an economic route to fuel supply needed by the electric utilities. SO_2 cleanup systems represent an established emission control technology, but one which has been employed in a limited number of applications. Still there are several SO_2 removal systems commercially available for removal of SO_2 gases from stack effluents. In each of these systems the objective is to produce a sulfur product (elemental sulfur, sulfuric acid, or sulfates) which may be removed mechanically from the system.

The most promising equipment which has been developed to be responsive to the problem of sulfate emissions from vehicles equipped with catalytic exhaust control devices is an SO_2 scrubber-muffler system. The unit operates on the basis that lead and sulfur will react with an alkaline molten carbonate placed in the scrubber. The unit also is highly effective for collection of total particulates. Limited testing has been performed with the scrubber-muffler device, and there are no immediate plans by its manufacturer to commit the concept to a production effort.

The other significant emission control options identified in the study include the standard air pollution control equipment now used extensively in many emission-control applications. Both baghouses and electrical precipitators may be incorporated as emission controls in cases where: 1) sources are currently uncontrolled by either of these two devices, or 2) when the efficiency of the existing precipitator or baghouse may be improved.

In the latter case, improving the collection efficiency may involve the replacement of an older, or less efficient unit, or the retrofit of an existing unit with additional equipment.

Control options classified as administrative policy were not addressed except very briefly, in this study. The implementation of shutdowns, partial or total, or relocation of process categories to locations where their generation of pollution is tolerable, is generally unfeasible from an economic standpoint. The actual disruption and socio-economic impact of this control option was not assessed quantitatively. It was assumed this approach would be considered as a last resort only, or possible as an option allowed the manufacturer in lieu of compliance with local emission regulations.

The cost effectiveness figures of Tables 3-5, 3-6 and 3-7 must be judged with some reservation. For example, the desulfurization control option may not be fairly represented by its cost effectiveness as applied to one source category alone since its implementation in the petroleum industry would produce reductions in SO_2 emissions whenever the associated petroleum products are used, and these reductions have not been credited to this control in Tables 3-5, 3-6 and 3-7. If desulfurization was adopted as a universal emission control method for the petroleum, fuel combustion, motor vehicle, and aircraft emissions source categories, its overall cost effectiveness would be markedly improved because of the overlapping control achieved among the various source categories.

The cost of controlling aircraft particulate emissions is greater than the control cost for any of the other control options. However it should be realized that these cost figures may be high, since the emission reductions attributed to the major combustion chamber redesign and ground operation modifications were conservative estimates, calculated to a baseline turbine engine which emits at "best emission rate" levels.

Obviously, the cost effectiveness of a given control option will vary accordingly to the degree of pollution which is available for cleanup. For example, SO_2 removal systems are shown to cost \$101 per ton of SO_2 removed when installed to manage emissions of metallurgical furnaces, but cost \$1540 per ton of SO_2 removed when treating effluent gases from stationary fuel combustion units. The difference in cost effectiveness is due in large part to the more concentrated emissions of SO_2 which are available for control from lead melting furnace effluents.

In general, the cost effectiveness of the various controls for the mobile emission sources appears least impressive. These controls involve the incorporation of retrofit technology to individual engines. Traditionally this type of control has been more expensive than those which are associated with stationary industrial process operations. The source emissions from the individual engines are relatively small, and there is therefore only minimal control potential available.

Within each process category there are unique air pollution problems which lend to treatment by the various alternative control measures in distinctly separate ways. Tables 3-5, 3-6 and 3-7 show that each of the significant control measures identified in the study is the most effective control approach available for at least one of the major source categories. In some cases, there are only minor advantages to be gained in emission control by using one control in preference to another. For example, desulfurization of petroleum products to very low sulfur content can result in effective emission control for SO_2 emissions from motor vehicle travel, fuel combustion, and petroleum refining operations. Slightly greater SO_2 control can be achieved for the former categories by utilizing other options, since they provide slightly greater removal efficiency for a given source (SO_2 muffler-scrubber for motor vehicles), or they enable control of a larger portion of the sources within the process category (SO_2 clean-up systems can effect emissions from refinery heaters as well as from boilers).

Clearly there are a great number of factors which must be examined to determine which of the emission control options may be the "most effective." First it is evident that emission controls for the four largest source categories cannot be evaluated on a mutually exclusive basis. If a single control method can be utilized throughout the source categories, its effectiveness would have to be judged according to its overall benefits, as well as the singular effects on each process category. Another factor in the fair appraisal of the candidate emission control methods involves technical feasibility. Some of the measures are in a higher state of technical refinement than others, and may therefore be more feasible in terms of immediate implementability. Another consideration in candidate appraisals must be the long-term potential it possesses for meeting emission standards which become increasingly more stringent with time. Several other factors are significant in the true appraisal of an emission prevention system. Identification of these factors, and their relative significance, is developed in the final control strategy formulation of the succeeding section of this report.

The following discussion (Sections 3.2.1 to 3.2.9) provides a brief narrative for the control options for each of the source categories. It includes a characterization of: 1) atmospheric emissions arising from the source category, 2) the prevailing emission control technology presently being utilized and 3) the control options and their impact on emissions.

3.2.1 Petroleum Industry

Emissions

The greatest quantity of air contaminants from the petroleum industry originates from refinery operations. The quantities of these emissions generated from refineries in the Four County Area are given in Table 3-9. Regeneration of the Catalyst utilized in the catalytic cracking of petroleum produces the largest portion of particulate, SO_2, and NO_x emissions

TABLE 3-9. EMISSIONS OF PARTICULATES, SO_2, AND NO_x FROM REFINERY OPERATIONS, FOUR-COUNTY AREA, 1972

Process	Emissions to Atmosphere Ton/Day	% Particulate Emissions in This Industry
PARTICULATES		
Petroleum Coke Operations	.7	22.4
Catalytic Cracking	2.2	73.2
Other	.1	4.4
TOTAL	3.0	
SO_2		
Catalytic Cracking	57.2	95.4
Other	2.8	4.6
TOTAL	60.0	
NO_x		
Catalytic Cracking	60.5	89.8
Other	7.0	10.3
TOTAL	67.5	

Source: Support Document #4,[4].

from this industry.

Existing Controls

Table 3-10 lists the type of control equipment currently being utilized to reduce particulate emissions of petroleum refining emission sources. It has been estimated by the Los Angeles APCD that over 90% of refinery particulate emissions are prevented from entering the atmosphere.

TABLE 3-10. CHARACTERIZATION OF CONTROL METHODS CURRENTLY UTILIZED IN PETROLEUM INDUSTRY FOR CONTROL OF MAJOR PARTICULATE EMISSION SOURCES, FOUR-COUNTY AREA, 1972

Process Operation	Actual Emissions lb/day[a]	Control	Average Efficiency
Petroleum Coke - Conveying	1020	None(except for wet treatment)	--
	15	Baghouse	89.6
Size Reduction	14	Baghouse	94.7
Storage	381	None	--
Catalytic Cracking	4400	Electrical Precipitation	95.0

[a] Figures are based on Reference [58], adjusted to reflect the overall Four-County emission totals as reported in Support Document #2,[2].

The traditional air pollution control devices, electrical precipitators, fabric filters, mechanical collectors, and wet scrubbers are used throughout the petroleum industry to control particulate emissions from large sources and a variety of small pollution generating sources. This equipment is suitable for reducing most emissions to negligible levels. However, despite levels of control which are in the neighborhood of 95% removal efficiency, the volumes of gases (up to 150,000 cfm) vented from a large regenerator still carry substantial emissions approaching the 30 lb/hr maximum (Rule #54, Solid Particulate Matter).

The major SO_2 and NO_x emissions of the petroleum industry result from catalytic regeneration operations, and are uncontrolled at present. There are currently no scheduled preventions planned for these sources.

Additional Control Options

Alternative controls which may be applied to refinery operations to reduce particulate and gaseous precursors emissions consist of both add-on equipment and process alterations.

- Control of Particulate Emissions:

  Retrofits to precipitators for improved performance is generally possible with newer equipment, but because of the rapid evolution of technology in the air pollution control industry, older generations of precipitators cannot be practically retrofitted. An additional problem in the retrofitting of existing precipitators is the space limitation constraining the retrofit. Typically most manufacturers have utilized all available space in the initial control equipment installation, such that retrofits may be extremely costly and probably less desirable than replacement alternatives.

  Due to a history of stringent air pollution controls in the Los Angeles Area, all local refineries have operated air pollution control equipment for several years. Most of this equipment has been updated in the last 3 to 5 years to reflect increasingly stringent emission regulations. Thus some of the equipment may be retrofitable to meet further demands for air pollution prevention, but it is likely that a large portion of the existing equipment would require replacement,due either to the economical or physical unfeasibility of configuration changes, or to the unavailability of adaptable retrofits on previous generation equipment.

The impact of equipping the refineries in the Los Angeles area with higher performance (99% removal) particulate emission control equipment is outlined in Table 3-5. The measure would provide for a 1.8 ton per day reduction in particulate emissions from refineries in 1977. The annual cost of the control is estimated at .25 million per year, or $512 per ton of particulates removed.

- Control of Gaseous Precursors:

There are many commercial methods for SO_2 removal from effluent gas streams, but to date relatively few of these have been thoroughly tested. Hence the operating and performance data associated with these recovery systems is very limited. Since refinery operations are not the primary contributor to SO_2 air pollution, none of the pilot SO_2 removal installations are directed at the removal of SO_2 from refinery regenerators. Most of the applications of commercial systems are now being used to recover sulfur from power plant stacks and sulfur recovery plant tail gases. However, a number of the SO_2 removal systems now being commercially promoted are applicable to a variety of flue gases containing SO_2. Particularly adaptable to a wide range of effluent gases are wet scrubbing techniques, such as the Wellman Lord process, the Double Alkali-system and the lime-scrubber technique.

The Wellman-Lord SO_2 removal system may be particularly well suited to application in refineries since its process produces a concentrated SO_2 gas, which can be delivered to sulfur recovery plants already existing at the refineries. While the quantity of sulfur which can be recovered from regenerator flue gases is not of appreciable magnitude to generate important economic benefits, the employment of the sulfur recovery using the Wellman-Lord principle avoids some of the supply and waste discard problems inherent in the wet scrubbing techniques. The Wellman-Lord process is now being utilized in 10 systems of different magnitude throughout the United States, and presently, 12 other systems are in construction. The manufacturer, Davy Power Gas Company, can guarantee an effluent

SO_2 concentration of less than 100 ppm. Obtaining this level of emissions would correspond to a 90% SO_2 emission reduction from the regenerator effluent stream.

Several other SO_2 removal systems may also be applied to the regenerator flue gases. A number of these may be able to remove over 90% of the SO_2, although their performance under the conditions of this application is unproven. These systems, notably the wet absorption methods, have been discussed in Support Document #4.[4].

The impact of add-on SO_2 removal systems to cracker units at the refineries in Los Angeles is given in Table 3-6. A 90% removal of SO_2 in the stack gases was assumed, providng a 51.4 ton per day reduction in SO_2 emissions from refinery emissions in 1977. The annual cost of these controls is estimated to be \$3.8 million per year, or \$193 per ton of SO_2 removed.

Another approach to the control of SO_2 emissions from refinery effluent streams is the desulfurization of those petroleum distillates targeted for catalytic cracking. The desulfurization of all those petroleum fractions fed to the catalytic cracker unit cannot be achieved with existing desulfurization equipment. The Chevron VGO Isomax Desulfurization Process is suitable for the desulfurization of catalytic cracker feed stock. Sufficient sulfur removal may be achieved to produce low sulfur products from the cracker and to reduce the sulfur oxides content in the regenerator stack gas to appreciably lower levels.

Construction of new desulfurization facilities with the capability of throughputting current cracker feed volumes and processing the feed to .05% sulfur will be required if refinery SO_2 emissions are to be reduced substantially by this route. The expected emission reductions from these facilities would amount to a prevention of 51.4 tons per day of SO_2 emitted to the atmosphere (Table 3-6). The cost of construction, operation, and maintenance of the desulfurization facilities would amount to an annual cost of \$19 million, or a cost of \$964 for each ton of SO_2 prevention.

3.2.2 Stationary Fuel Combustion

Emissions

The most significant emissions arising from stationary fuel combustion **are** sulfur dioxide gases. Combustion sources presently account for about 46% of all atmospheric SO_2, 21% of the particulate emissions, and 20% of the NO_x. These emissions are distributed throughout the Four County Area.

Emission rates vary among the various types of stationary combustion equipment. The emissions are dependent on type and size of equipment, the method of firing, and the degree of maintenance. Table 3-11 provides a summary of various types of fuel burning equipment found in the South Coast Air Basin. The smaller units (domestic and commercial) burn entirely on a schedule of natural gas and the larger industrial units burn either natural gas or fuel oil. Many industrial units are equipped for fuel conversion, and still others are able to burn both natural gas and fuel oil simultaneously.

TABLE 3-11. SUMMARY OF FUEL BURNING EQUIPMENT

Equipment Category	Description
Power Plants	Power plant boilers
Industrial	Large and medium sized boilers, refinery heaters, stationary internal combustion engines
Domestic & Commercial	Residential, combustion (space heaters, water heaters, ranges), and small commercial boilers.

The effect of fuel type on emissions from combustion units of power generating stations is illustrated in Table 3-12. Emission rates of both nitrogen oxides and particulate matter are substantially higher when burning fuel oil than when burning natural gas. There are essentially no emissions of sulfur dioxide when natural gas is burned.

TABLE 3-12. POLLUTANT EMISSIONS BY FUEL TYPE FOR BASIC COMBUSTION CATEGORIES IN FOUR-COUNTY AREA

Year	Pollutant	Power Plant			Industrial			Domestic
		Nat.Gas	Oil	Total	Nat.Gas	Oil	Total	Nat.Gas
1972	Particulates	1.5	20.8	22.3	6.6	5.5	12.0	10.6
	SO_2	1.1	179	180	.3	27.3	27.6	.3
	NO_x	44.0	49.5	93.3	26.4	88.4	114.8	74.1
1977	Particulates	.1	35.9	36.0	3.7	32.2	35.9	11.6
	SO_2	.2	292	292	.2	81.0	81.2	.4
	NO_x	6.2	129	135	31.0	445	476	61.1
1980	Particulates	.1	36.7	36.8	4.5	28.0	32.5	12.3
	SO_2	.2	304	304	.2	85.0	75.2	.4
	NO_x	7.6	135	143	37.0	388	425	61.1

Source: Reference [2].

Existing Controls

Applied emission control technology for combustion units includes: 1) fuel modification, 2) burner design and operation techniques, and 3) removal of pollutants from stack gases. The effectiveness of fuel modification for pollution control has been illustrated in Table 3-12. This pollution control approach is used whenever the supply of natural gas permits. However the effectiveness of this approach will be limited in future years due to the smaller quantities of fuel gas available.

Stack treatment for removal of pollutants from combustion systems has not been employed in the Four-County Area. In the past, emission regulations have been met through the use of clean fuels and burner adjustments. Projected regulations are not expected to provoke any changes in this status.

Reduction of NO_x in existing boilers large enough to be under jurisdiction of Rule 68 (Fuel Burning Equipment) has been accomplished by operations changes or combustion modifications. These control methods are applicable to smaller burner units but are not required under present regulations. Rule 68 limits NO_x emissions to low levels (325 ppm stack gas concentration) and is targeted for larger boilers at the power plants. Control methods utilized by Edison Company in complying with Rule 68 include: 1) off stoichiometric diffusion flame operation, 2) two-stage combustion, and 3) flue gas recirculation (these methods are discussed in the next section). The overall reduction of NO_x emissions due to these controls from all units tested at Edison Plants was over 50 percent,[59].

Additional Control Options

The technology available to reduce emissions discharged by fuel combustion consists of equipment modification and operational changes, flue gas treatment, and fuel substitution. Except for fuel substitution, no single control method is effective in preventing emissions of all pollutant species (particulates, SO_2, NO_x).

- Control of Particulates

  With conventional use of burner equipment, particles in the flue gases can generally be maintained well below the emission standard of .3 grain per scf of exhaust (Rule 53b). Given proper operation of the combustion burners, the rate of particulate emissions depends primarily on fuel type. The efficient burning of a common heavy residual oil of .1% ash results in a stack gas concentration of only .03 grain per scf. There is no measurable inorganic ash in exhaust gases from the combustion of natural gas. Low sulfur oil contains small amounts of ash. Hence, the exhaust gases of typical fuel burning is not likely to exceed local standards.

While the relative emission rate of particulates from fuel combustion is low, the immense volumes of exhaust gases produced by large oil burning units result in appreciable discharges of particulate matter to the atmosphere. Because of the large volumes of exhaust and the small size of particulates in the gas stream, only the electrical precipitation and fabric filter are suitable candidate controls for this application.

A removal efficiency of 99.9% is typically obtained with a fabric filter for particles in the submicron range. By comparison, electrical precipitators which collect submicron size particles at over 95% efficiency require additional equipment at greatly increased costs. However fabric filters have not been used extensively to handle applications in which the gas volumes to be treated are as large as that emitting from a utility boiler. Manufacturers of fabric filters state this is because the fabric filter is not competitive when installed for such immense effluent volumes.

The impact of equipping oil-burning equipment in the Four County Area with high efficiency (95% removal) electrical precipitators, or fabric filter baghouses (99.9% removal) on fuel burning emissions is shown in Table 3-5. Table 3-13 summarizes the cost of the two particulate control options for oil-burning combustion equipment. The electrical precipitator is slightly more cost effective as a control for larger fuel burning equipment, and equally cost effective to the fabric filter when processing the smaller effluent volumes associated with boilers of less thermal rating. Since the baghouse has not been used extensively to control emissions from large boiler units, it appears that its selection for this application would be unwarranted. The baghouse is significantly more cost effective as a collector for refinery heater emissions, and should probably be recommended for this application.

TABLE 3-13. COST OF PARTICULATE EMISSION CONTROL FOR OIL-BURNING COMBUSTION EQUIPMENT, 1977

Equipment	Number of Units	Control	Cost in Millions of Dollars: Initial Purchase & Installation Cost x 10^6	Operation Cost Increase	Annualized Cost Increase	Cost per Ton of Particulate Reduced
Large power plant boilers (Average size = 260 MW)	35	high efficiency electrostatic precipitator	48.1	7.0	12.6	$1452
	"	high efficiency baghouse	38.5	10.5	15.0	1671
Small power plant boilers (Average size = 65 MW)	49	high efficiency electrostatic precipitator	13.5	2.0	3.6	932
	"	high efficiency baghouse	12.2	2.2	3.6	904
Large non-power plant boilers (Average size = 78 MW)	152	high efficiency electrostatic precipitator	68.4	9.1	17.1	1530
	"	high efficiency baghouse	60.8	11.4	18.5	1590
Refinery heaters (Average size = 6.5 MW)	220	high efficiency electrostatic precipitator	28.6	3.3	6.7	2410[e]
	"	high efficiency baghouse	28.6	2.1	5.4	1863

Source: Reference [4].

- NO_x Control:

The control of NO_x emissions from combustion units is primarily a function of the control of temperature and residence time in the primary flame zone. Both of these functions can be managed by modification of operating conditions and by modification of design features in existing combustion units. Numerous methods of modifying the operating conditions have proven successful and may be adopted for use in existing combustion units. These include: 1)low excess air firing, 2) two stage combustion, 3) flue gas recirculation, 4) steam or water injection, and 5) direct temperature control. Design modifications which may be utilized for NO_x control generally involve an alteration in the burner and furnace configuration, or the location and spacing of burners.

The effect of implementing the various NO_x control alternatives for combustion units in the Four-County Area is summarized in Table 3-14. The most feasible combinations of NO_x control options have been examined. As a single control, low excess air firing was considered the most appropriate option, due to its cost advantages over other equally effective options (such as direct temperature control, or flue gas recirculation). Low excess air firing results, on the average, in 40% reductions of NO_x emissions from commercial and industrial boilers. These boilers generally are fired to 15-30% excess air, and may be reduced to 2-6% according to tests. In power plant boilers less than 1775 MBTU/HR, excess air firing is typically 5-15%, and NO_x reductions from lower excess air firing averages about 30%. Tests conducted with refinery heater units have confirmed 40% reductions are attainable,[60].

To develop additional NO_x removal, flue gas recirculation may be used with low excess air firing to achieve NO_x reductions of 70% from boilers. The feasibility of utilizing flue gas recirculation in refinery heaters as a retrofit is not clear at this time. There is currently evidence which indicates this approach requires development of an entire new heater design. Hence, this control option was not considered for implementation on refinery heaters,[60].

TABLE 3-14. THE EFFECT OF NO_x EMISSION CONTROLS ON FUEL COMBUSTION EQUIPMENT, FOUR-COUNTY AREA

Combustion Unit Description	Average Size MBTU/Hr	Projected NO_x Emissions Tons/Day 1977	Projected NO_x Emissions Tons/Day 1980	Control Measure	NO_x Reduction In 1977 Percent	NO_x Reduction In 1977 Tons/Day	Cost/Ton of NO_x Reduction
1. Large power plant boilers (1825-3550 MBTU/hr)	2630	105	111	None-already equipped with advanced combustion control (emissions are controlled to about 20% of uncontrolled emissions level)	-	0	0
2. Small power plant boilers (100-1775 MBTU/hr)	660	30	32	Low excess air firing & flue gas recirculation	30 50	9 15	$200 450
3. Large non-power boilers (30-400 MBTU/hr)	80	118	105	Low excess air firing & flue gas recirculation	40 70	47 83	22 127
4. Medium sized boilers (2-30 MBTU/hr)	9	205	183	Low excess air firing & flue gas recirculation	40 70	82 144	694 870
5. Large refinery heaters (90-290 MBTU/hr)	120	38	34	Low excess air firing	40	15	27
6. Small refinery heaters (5-90 MBTU/hr)	45	27	24	Low excess air firing	40	11	226
7. Large stationary internal combustion engines (> 300 H.P.)	700 H.P.	69	61	Water injection or exhaust gas recirculation	75	52	13
8. Small compressor engines (< 300 H.P.)	200 H.P.	19	17	Water injection or exhaust gas recirculation	75	14	37
9. Domestic (residential) fuel combustion (space & water heaters, ranges)	-	46	46	None	-	0	-
10. Small commercial and industrial boilers (2 MBTU/hr)	-	15	15	None	-	0	-

Source: Reference [47].

Many controls have already been applied in power plants to comply with the NO_x emission reductions required by Rule No. 68. These control options are applicable to large utility boilers and have not been considered as candidate alternatives in Table 3-14. The compact size and limited number of burners in other boilers and in heaters render these options technically unretrofittable for applications other than large utility boilers. These alternatives include two stage combustion, relocation of burners, modification of burner spacing, and others.

There are currently no retrofit controls developed to manage the NO_x emitting from residential fuel combustion, and small industrial and commercial boilers. New units may be designed to control NO_x emissions, but because retrofit controls would require relatively extreme costs for these small units, they would probably not be politically acceptable. Hence, no controls have been considered in Table 3-14 for these smaller source categories,[61].

Stationary internal combustion engines (used primarily in gas and oil industry for gas compression) can be retrofitted with water injection or exhaust gas recirculation equipment to obtain NO_x emission reductions of about 75%. The two approaches are equally cost effective. Stochiometric fuel adjustments have been shown effective in reducing NO_x emissions to 70%, but the associated loss in power and fuel economy make this control method less desirable than water injection or exhaust gas recirculation,[60],[62],[63].

The cost effectiveness of the various NO_x control options for combustion units in the Four-County Area is summarized in Table 3-14. The least costly control alternative consists of either water injection or exhaust gas recirculation, applied to stationary internal combustion engines. This measure may be incorporated on large engines at a cost of only $13 per ton of NO_x emissions prevented. The most costly NO_x control option is also the most significant in terms of overall NO_x emissions, low excess air firing and flue gas recirculation in medium sized boilers. The cost for this retrofit is $870 per ton of NO_x removed.

- Control of SO_2:

An obvious means of reducing emissions of SO_2 from fuel combustion is to remove the sulfur from the fuel. Present regulations permit .5% sulfur content in fuel oil (Rule 62). This standard was initially adopted with the intention of motivating utility companies to substitute natural gas for fuel oil. At the time the regulation became law, natural gas was more abundant and less expensive than the low sulfur (.5%S) fuel oil. Hence, the desired switch to gas use occurred quickly and emissions from power plants decreased appreciably. These gains in air pollution control have diminished in recent years and are expected to be realized even less because of the continuing shortage of natural gas, and the increased burning of low sulfur fuel oils.

Currently, low sulfur fuel oils of .5% sulfur content are typically produced by: 1) desulfurization of heavy distillate to produce very low sulfur blend stocks, and 2) blending these low sulfur stocks with the high sulfur residuum portion of the barrel. Low sulfur processing of the residuum has not been practiced extensively, and it is becoming evident that this will be required if petroleum products are to be manufactured according to the increasingly stringent standards. Several processing schemes are being proposed as possible routes to very low sulfur fuel oils. Two of the most feasible methods were discussed in Section 3.1. These methods have been tested in pilot development and are termed: 1) VGO Isomax Plus Solvent Deasphalting, and 2) VGO Isomax Plus VRDS Isomax. Both of these processes lend to stepwise construction at the refinery and are integrateable with existing refinery equipment. The level of sulfur content obtained by these processes is .05%. Another obvious means of controlling SO_2 emissions is incorporation of SO_2 removal systems in the stacks.

Several SO_2 cleanup processes are commercially available to manage emissions from fuel-burning combustion unit stacks. These methods are discussed in Section 3.1. Several installations are now operating at various power plants throughout the nation to control SO_2 emissions within new and more stringent state pollution standards. Many of the SO_2 removal processes are being tested under pilot projects (mainly utility boiler stacks) sponsored by the EPA

Comparative evaluations of the various SO_2 cleanup processes is not possible since many problems still remain to be identified during development and commercial operation. It seems certain, however, that a number of processes will be available to provide guaranteed reductions of 90% for a variety of applications,[64].

The effect of implementing the potential SO_2 control methods on fuel combustion emissions throughout the Four-County Area is shown in Table 3-6. Both the option of add-on SO_2 removal system and desulfurization of fuel oil offer the same emission control effectiveness in the long term. However, desulfurization of fuel oils is not expected to affect emissions from refinery heaters, since these units operate primarily on refinery make gas and fuel oil. These fuels are generally heavy residual oils and high sulfur content gas streams. They are not practically marketed or further processed, and are therefore burned in the heating equipment as an economical expedient. Unless these refinery by-product gases and oils can be disposed of alternately, it does not appear feasible that low sulfur supply stock could be used in its place. Hence, only flue gas cleanup systems were considered a candidate control for refinery heater emissions.

Implementation of either control (desulfurization or stack SO_2 removal) would result in substantial preventions of SO_2 entering the atmosphere. The option of fuel oil desulfurization cannot be implemented totally by 1977 due to lead time required to construct the processing facilities. However, by 1980, this option can be fully implemented.

Desulfurization of fuels to low sulfur levels created beneficial side effects as the ash content is reduced concurrently with sulfur removal. Consequently, particulate emissions are reduced when low sulfur fuels are burned. Particulate emissions originate from unburned hydrocarbons as well as the inorganic ash contained in the fuel, but when combustion conditions are adjusted properly, the ash content is the main factor causing particulate emissions. Most of the materials found in stack emissions consist of metal oxides, sulfates, and chlorides, all of which are directly attributable to the sulfur and ash content of the fuel. Therefore it may be expected that the combustion of very low sulfur fuel oil from new desulfurization facilities will result in appreciable particulate emission reductions. These reductions have been estimated in Table 3-6 (based on source measurement data of the Los Angeles APCD,[65], and fuel analysis data of residual fuels used in Los Angeles,[66]). It was estimated that a 40% reduction in particulate emissions may be obtained when burning the higher quality very low sulfur fuels manufactured by the new refinery equipment. These fuels will contain a negligible quantity of ash,[67].

The cost effectiveness of implementing the candidate SO_2 controls is shown in Table 3-6. Desulfurization of fuel oils is the most cost effective alternative at $1040 per ton of SO_2 emissions prevented. This is about 35% less than the cost of adding stack SO_2 removal processes to all oil burning combustion units in the Four-County Area. However, desulfurization of fuel oils itself does not obtain the same total prevention as overall stack control since it is not applicable to refinery heaters (in which refinery make gases are disposed of). Hence, stack SO_2 add-on control must be used with fuel desulfurization to obtain 90% prevention of SO_2 emissions.

- Fuel Substitution - A Control for Particulates, SO_2 and NO_x:

The impact of converting to methyl-fuel in fuel burning units in the Four-County Area is shown in Table 3-15. The effect is dramatic as the alternate fuel burns virtually pollution free, except for small amounts of NO_x.

The cost evaluation shown in Table 3-5,3-6 and 3-7 can be considered preliminary. It does not include consideration of adaptions which will be required for fuel burning equipment when converting from fuel oil to methyl-fuel (equipment such as fuel pumps and nozzles will require modification). However, most of these adaptions are not expected to incur substantial expense, and have therefore been neglected in prior cost estimates.

TABLE 3-15. IMPACT OF CONVERSION TO METHYL-FUEL IN COMBUSTION UNITS IN FOUR-COUNTY AREA

	Particulates	SO_2	NO_x
Emissions expected in 1980 from combustion with burning fuel oil	65	379	431
Emission reductions when methyl-fuel is used as fuel, 1980	65	379	328*

*Based on emission rate of 1000 lbs/NO_x per 1000 equivalent barrels of natural gas, and projected fuel re requirement of 111 x 10^6 barrels fuel oil in 1980,[52],[53],[68].

The preliminary data demonstrate clearly that methyl-fuel should be given serious consideration as: 1)a clean burning fuel which would solve many air pollution problems, and 2) an economical fuel substitute which can be manufactured from domestic raw materials, without dependence on foreign petroleum stocks. The lead time to build a methyl-fuel producing plant, 3-4 years, would pose serious difficulties in imposing fuel substitution plans in the near term. In addition, the political and social disruptions resulting from an enforced imposition of fuel substitution would make a near term conversion unfeasible.

3.2.3 Minerals Industry

Emissions

Most of the emissions arising from the mineral industry in the Four-County Area are from twelve basic process categories. These are aggregate operations, abrasive blasting, clay and clay related operations, cement operations, asphalt saturation, glass and frit operations, concrete batching, sand handling, asphalt batching, foundry sand operations, catalyst production, and lime and limestone operations. Emissions are generally in the form of dust from screening, crushing, storage, and handling operations, where the material being handled is dry. Those emissions which are most difficult to control are those emitted from processes such as quarrying, yard storage and transportation.

12.3 tons/day of particulate emissions come from mineral operations in the Four-County Area (see Table 3-5). This amount is 6% of the total particulate emissions from all emission source types in this area. NO_x and SO_2 emissions from mineral operations are negligible in the Four-County Area.

Existing Controls

Table 3-16 shows a summary of emission controls for each of the twelve major mineral operation categories. In the table, each emission control method as it is applied to each category is listed. The range of efficiency and average efficiency is shown for each control method along with the amount of particulates emissions for each category that comes from sources which are controlled by each method. It can be seen that the most frequently applied control devices in the mineral industry are the fabric filter and mechanical collector. The use of high efficiency particulate control devices have been used whenever economically feasible to control emissions at the larger point sources. Because the industry typically handles immense process volumes, the preventions accomplished by the emission control equipment has been substantial - over 100 tons per day.

According to the APCD emissions file, many mineral operations are uncontrolled. The data of Table 3-16 indicates that a total of approximately four tons per day of particulate matter is emitted from uncontrolled mineral operations. However, it has been found through further investigations that many of these so called uncontrolled sources are, in fact, controlled. Many operations involving aggregates, clay products, cement, concrete and

TABLE 6-2. SUMMARY OF EMISSION CONTROLS CURRENTLY UTILIZED IN MINERALS INDUSTRY OF LOS ANGELES COUNTY

Process	Control	Particulates Efficiency of Control Range	Particulates Efficiency of Control Average	Lbs/Day Emitted	Lbs/Day Prevention
1. Aggregate Operations	Dry Filter, Baghouse	0	0	4472	8771
	Dry Filter, Other	50-99	98	179	29
	Dry Inertial Separator	90-95	94	60	940
	Dust Suppression System	90-93	93	566	7520
	Scrubber	20-95	52	686	743
2. Abrasive Blasting	None	0	0	104	0
	Dry Filter, Baghouse	98	98	5.2	255
	Dry Filter , Other Separator	99	99	4701	465400 2793
	Scrubber	97			841
	Mist Collector	98	98	33	1617
3. Clay and Clay Related Operations	None	0	0	971	0
	Dry Filter, Baghouse	90-99	97	601	19432
	Dry Inertial Separator	98	98	21	1029
	Scrubber	0-80	80	165	660
4. Cement Operations	None	0	0	238	0
	Dry Filter, Baghouse	90-99	99	1430	141570
	Dry Filter, Other	0-99	69	9	20
5. Asphalt Saturation	None	0	0	244	0
	Dry Filter, Other	97	97	249	8051
	Electrical Precipitator	93	93	493	6550
	Mist Collector	89	89	204	1651
	Scrubber	75	75	207	621
6. Glass and Frit Operations	None	0	0	804	0
	Dry Filter, Baghouse	87-99	96	159	3816
	Spray Booth Ceramic	0	0	30	0
	Dry Inertial Separator	93	93	62	824
	Scrubber	0-87	85	221	1252
7. Concrete Batching	None	0	0	522	0
	Dry Filter, Baghouse	96	96	195	4680
	Dry Filter, Other	0	0	2	0
	Scrubber	50	50	69	69
	Dust Suppression System	98	98	276	13524
8. Sand Handling	None	0	0	269	0
	Dry Filter, Baghouse	99	99	529	52371
	Dry Inertial Separator	83	88	9	44
	Scrubber	78	78	116	411
9. Asphalt Batching	Dry Filter, Baghouse	99+	99+	143	14160
	Scrubber	99+	99+	635	62865
10. Foundry Sand Operations	None	0	0	509	0
	Dry Filter, Baghouse	93-98	97	58	1075
	Scrubber	79-89	88	102	748
11. Catalyst Production	None	0	0	13	0
	CO Boiler Cyclone	0	0	20	0
	Dry Filter, Baghouse	99-99+	99	7	693
	Scrubber	81	81	579	2468
	Incineration, Direct Flame	98	98	47	2303
12. Lime Limestone Operations	None	0	0	94	0
	Dry Filter, Baghouse	80-99	98	351	17199
	Scrubber	98	98	124	6076
Totals				21667	853871

Notes:

1. Where control is designated as "none" it is probable that wetting techniques are being utilized to reduce dust emissions (see text).

Source: Reference [92].

sand are conducted while the material is wet or damp. Wetting the material suppresses dust emissions, and is an effective and economical control not identified in the available data.

Additional Control Options

The vast majority of significant particulate emission sources of the mineral industry are controlled by standard collector devices. Improving emission control in this industry would necessarily involve the employment of additional devices (such as baghouses, scrubbers, and cyclones) at the numerous "uncontrolled" process transfer points. Currently, dust emissions from various transfer operations are minimized by insuring all materials are wetted as they are processed from one operation to another. Of the four tons per day of particulates arising from the numerous uncontrolled point sources, it is probable that nearly all of it could be collected with additional control equipment installations. However, it is clear that such an installation program would involve severe economic penalties.

It is significant that wetting practices have proven effective in reducing dust emissions to levels complying with APCD regulations. The emissions are not visible (meeting with Ringleman Rule No. 50), do not pose a nuisance (Rule 51), do not exceed the maximum permissible concentration (Rule 52), and do not violate the process weight rule (Rule 54). If any source has, in the past, violated any of these regulations, it has since been equipped with additional particulate emission controls or been given a variance. Hence the controls which are being applied at present have for the most part been applied according to the present concept of particulate emission control and the associated technology.

While economically it appears clear that more stringent controls cannot be feasibly imposed on the mineral industry, there are in addition, inherent limitations in the emission inventory which make untenable the proposal for increased control expenditures. The quantification of particulate emissions generated by various points in a mineral processing system is extremely difficult, if not impossible. The "average" emission rates used in the inventory tabulation are presumed to reflect varied process conditions and configurations which in many cases have never been investigated empirically or theoretically, and which in many cases, have been modified significantly since the initial analysis.

It appears that if improvements can be made to the level of existing controls, they should be directed toward good practice, proper operation, and maintenance of control efficiency. Control equipment should be carefully inspected prior to initial installation and after regular maintenance to insure that no production faults have occurred, and that adequate control efficiency is being attained.

3.2.4 Aircraft Operations

Aircraft Emissions

The most significant type of emissions deriving from aircraft operations are particulates. Figure 3-4 shows that particulate emissions from aircraft accounted for 7% of the total particulate emissions discharged to the atmosphere of the Four-County Area in 1972, and are expected to account for 15% of the particulate discharges by 1980. Aircraft operations accounted for a small portion of the gaseous particulate precursors emitted in 1972, but are expected to exercise a more significant role in this type of pollution by 1980.

The magnitude of atmospheric pollution arising from piston aircraft

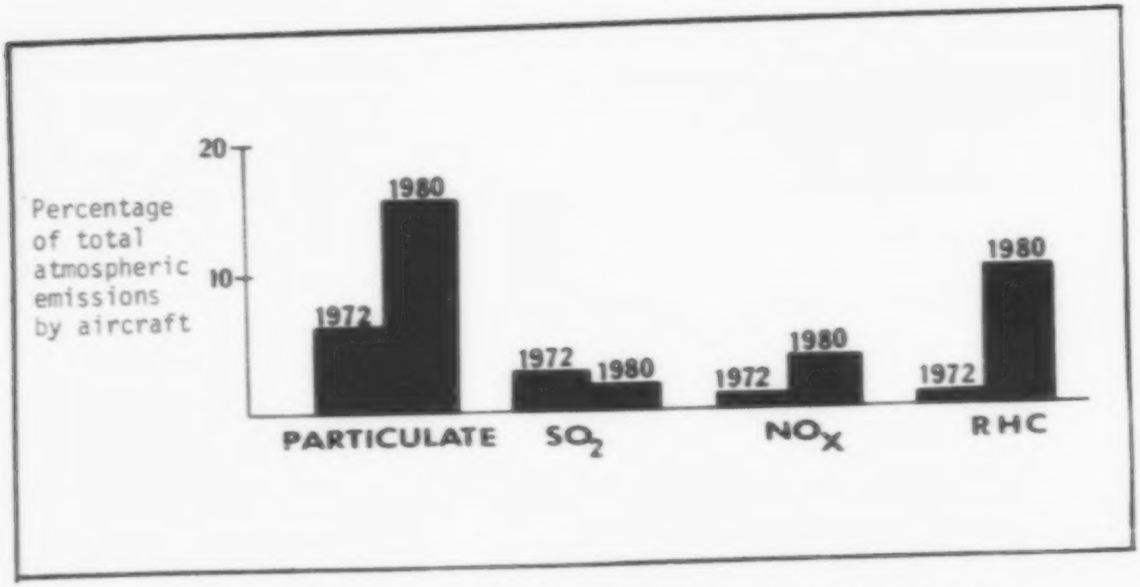


Figure 3-4. Role of Aircraft Emissions in Atmospheric Pollution of Four-County Area.

and jet aircraft in the Four-County Area is shown in Table 3-17. Emissions from both piston and jet powered aircraft are expected to increase in future years, owing to the imminent growth rates of these motive types and the limited pollution control currently scheduled for implementation. Due to the increasing predominance of jet powered aircraft operations at the various airports, piston aircraft are expected to contribute a lesser percentage of the anticipated aircraft pollution.

TABLE 3-17. AIRCRAFT EMISSIONS, PRESENT AND PROJECTED, PISTON AND JET

Year	Engine Type	Particulates	SO_2	NO_x	RHC
1972	jet	11.5	3.4	12.4	9.9
1972	piston	3.5	.2	6.2	5.8
1977	jet	22.2	6.5	23.9	19.0
1977	piston	4.6	-	8.3	7.7
1980	jet	32.8	9.6	35.4	28.1
1980	piston	5.5	-	10.0	9.0

Source: Reference [4].

Emission Controls

Congressional studies (1969) evolving from the Air Quality Act of 1967 identified visible emissions as the most significant problem associated with aircraft, and as a result, three airlines voluntarily agreed to retrofit the widely-used Pratt and Whitney JT8D engines with smoke combustors by the end of 1972. The smoke combustor retrofit program was further extended to include all JT3D engines by 1976. Since air operation activity at the major airports is predominantly composed of aircraft powered by either JT3D or JT8D engines, it is estimated that the reduced smoke combustion retrofit substantially affected the quantities of pollutants emitting from aircraft acitvity. Hydrocarbon emissions were the most drastically affected by this retrofit program, while particulate emissions were also significantly reduced.

Standards requiring major changes in engine emission characteristics were promulgated for turbine engines on July 17, 1973. The standards consist basically of the following control categories:

1. Retrofit control of smoke emissions and fuel venting for in-use turbine engines.
2. Standards in 1979 to reduce emissions for new turbine and piston engines built in 1979 and after.
3. Standards in 1981 to reflect emission reductions achievable with new large aircraft engine designs.

Alternative Control Options

The current emission standards will result in substantial emission reductions only after attrition of pre-1979 engines. Additional controls will be required to bring about significant near-term reductions. Feasible control technology which may be applied includes:

- Modification of ground operations
- Engine modification (retrofits) for turbine and piston fleets.

- Retrofit Alternatives for Turbine Engines:

The EPA has studied the technology which may be applied to reduce emissions from turbine aircraft. Engine modification methods feasible for turbine engines as retrofits are described briefly in Table 3-18. These modifications can be combined (with the exception of T4 and T6) to achieve increased emission control effectiveness.

The estimated effectiveness from these measures are presented in Table 3-19, in terms of the reductions attainable from the lowest current emission rates realistically obtainable for the given turbine engine class. This baseline level is equivalent to the emissions resulting when an engine is well maintained and operates with control method tl (smoke combustor). The basis for the effectiveness estimates are document in Support Document #4, [4].

The overall reduction to atmospheric emissions by implementation of the turbine engine modifications depends on the mix of turbine aircraft classes operating at the various airports throughout the South Coast Basin. In addition, the overall reductions also depend on the mix of engine makes within each engine class, and the degree to which each of these contribute total emissions during the various segments of the idle-take-off approach cycle. The engines representative of the turbine engine classes are the JT3D, JT8D, and JT4A engines. Currently these turbine engines generate approximately 90% of all polluting emissions from turbine engines. The importance of the JT9D engine (jumbo aircraft) is expected to increase in the future emission profile.

Emissions for the different engines vary for the different modes of operation. Table 3-20 demonstrates that particulate and SO_2 emissions from jet aircraft engines are most conspicuous during the taxi and idle modes. This is due primarily to the fact that emissions in this mode are sustained over approximately 80% of the total LTO cycle. Oxides of nitrogen emissisons are most prevalent during the higher loading conditions of takeoff and climbout. The distributions are based on actual field measurements performed by the LAAPCD of aircraft operating at Los Angeles International

TABLE 3-18. ENGINE MODIFICATIONS FOR EMISSION CONTROL FOR EXISTING AND FUTURE TURBINE ENGINES

Control Method	
Existing engines	
t1 - Minor combustion chamber redesign	Minor modification of combustion chamber (smoke combustor retrofit) and fuel nozzle to achieve best state-of-art emission performance.
t2 - Major combustion chamber redesign	Major modification of combustion chamber and fuel nozzle incorporating advance fuel injection concepts (carburetion or prevaporization).
t3 - Fuel drainage control	Modify fuel supply system or fuel drainage system to eliminate release of drained fuel to environment.
t4 - Divided fuel supply system	Provide independent fuel supplied to subsets of fuel nozzles to allow shutdown of one or more subsets during low-power operation.
t5 - Water injection	Install water injection system for short duration use during maximum power (takeoff and climb-out) operation.
t6 - Modify compressor air bleed rate	Increase air bleed rate from compressor at low power operation to increase combustor fuel-air ratio.
Future engines	
t7 - Variable-geometry combustion chamber	Use of variable airflow distribution to provide independent control of combustion zone fuel-air ratio.
t8 - Staged injection combustor	Use of advanced combustor design concept involving a series of combustion zones with independently controlled fuel injection in each zone.

Source: Reference [69].

TABLE 3-19. EFFECTIVENESS OF ENGINE MODIFICATION IN CONTROL OF EMISSIONS FROM TURBINE ENGINES, BY OPERATING MODE[a]

Control Method	Engine Class	Pollutant	Mode		
			Idle/taxi	Approach	Takeoff
t2[b]	T1	DP	0.5	0.5	0.5
t2	T1	NO_x	NC[c]	NC	0.5
t2	T2	DP	0.5	0.5	0.5
t2	T3	NO_x	NC	NC	0.5
t3	T1	THC	NC	NC	0[d]
t3	T2	THC	NC	NC	0[d]
t3	T3	THC	NC	NC	0[d]
t4	T1	CO	0.25	NC	NC
t4	T1	THC	0.25	NC	NC
t4	T2	CO	0.25	NC	NC
t4	T2	THC	0.25	NC	NC
t4	T3	CO	0.25	NC	NC
t4	T3	THC	0.25	NC	NC
t5	T1	NO_x	NC	NC	0.1
t5	T2	NO_x	NC	NC	0.1
t5	T3	NO_x	NC	NC	0.1
t6	T1	CO	0.5	NC	NC
t6	T1	THC	0.5	NC	NC
t6	T2	CO	0.5	NC	NC
t6	T2	THC	0.5	NC	NC
t6	T3	THC	0.5	NC	NC
t6	T3	CO	0.5	NC	NC

[a] Emission rate is fraction of best current rate assumed to be attainable through minor combustion chamber redesign and with control method cited.

[b] t2 = Major combustion chamber redesign
t3 = Fuel drainage control
t4 = Divided fuel supply system
t5 = Water injection
t6 = Modify compressor air bleed rate

[c] NC indicates no change

[d] Refers to raw fuel drainage only

Source: Reference [69].

Airport. It was presumed that these figures could be used to devise representative modal emission distributions.

TABLE 3-20. MODAL EMISSIONS DISTRIBUTION FOR PRINCIPAL JET ENGINES IN USE

Pollutant	Turbine Engine	Engine Class	Percentage of Emissions per LTO		
			Idle-Taxi	Approach	Takeoff and Climbout
Particulates	JT3D	T2	47	12	41
	JT8D	T2	36	37	27
	JT4A	T2	70	11	18
	JT9D	T3	55	21	24
SO_2	FT3D	T2	42	18	40
	JT8D	T2	39	28	33
	JT4A	T2	46	18	37
	JT9D	T3	39	22	39
NO_x	JT3D	T2	12	14	74
	JT8D	T2	15	30	55
	JT4A	T2	15	17	68
	JT9D	T3	9	15	76
THC	JT3D	T2	95	3.1	1.2
	JT8D	T2	95	3.1	1.2
	JT4A	T2	90	4	5
	JT9D	T3	60	18	22

Calculations for modal distribution are based on Reference [70] and [71].

Based on the JT8D and JT3D, the most widely used engines in the turbine fleet, the estimated relative effectiveness of the retrofit controls is as shown in Table 3-21. Actual emission reductions for the Four-County Area have been calculated from these figures and are shown in Tables 3-5,3-6 and 3-7.

TABLE 3-21. IMPACT OF ALTERNATIVE CONTROL ON OVERALL JET AIRCRAFT EMISSIONS

Control Method	Percent Reduction in Overall Engine Emissions			
	Particulates	THC	NO_x	SO_2
t2	50	NC	34	NC
t3	NC	1[a]	NC	NC
t4	NC	71	NC	NC
t5	NC	NC	58	NC
t6	NC	48	NC	NC

NC = No change

[a] Refers to reduction due to elimination of raw fuel drainage only, which constitutes a small portion of emissions in takeoff mode.

[b] New design standard for engines manufactured in 1979 and after (not a retrofit measure).

Presently, the EPA is proposing that all aircraft engines be retrofitted to 1979 standards by 1979. The technical feasibility of this proposal is unclear since alternative retrofits are not in a good state of refinement at this time,[72]. Few of the control methods have been developed or applied to aircraft engines. Table 3-22 lists the development time requirements for each of the control methods. A major consideration in development time consists of the maintenance facilities and procedures accompanying the retrofitting equipment. The minimum time for implementation of most of the emission control methods for turbine engines is estimated to be two and one-half years.

TABLE 3-22. TIME AND COSTS FOR MODIFICATION OF CURRENT CIVIL AVIATION ENGINES

Control Method	Development Time, Years	Development Cost, 10^6 Dollars	Implementation Cost, 10^6 Dollars
Major combustion chamber redesign	2.5 to 7.5	74	665
Fuel drainage control	1 to 2.5	1.5	5.4
Divided fuel supply	5 to 7.5	84	102
Water injection	2.5 to 4	25	175
Compressor air bleed	4 to 6.5	90	58

Source: Reference [69].

Of the potential methods for aircraft emission control, the retrofitting of in-use engines is the most costly. The cost of modifying existing designs for emission control in new engines is approximately one-half of that incurred by retrofitting. The incorporation of new control technology during new engine design incurs the least cost, estimated at a 3-4% increase over the base engine cost. Table 3-23 provides cost estimates for implementing the various retrofit control methods in the Four-County Area. Implementation includes initial installation of the control method on all engines of a given class and the additional effort required for the control method throughout the remaining life of the engines (assuming 10 year life). The only measure affecting particulate emissions is the major combustion chamber redesign, which requires a cost of $4100 per ton of particulate recovered. NO_x emissions are reduced most drastically by water injection control, at a cost of $820 per ton of NO_x controlled.

TABLE 3-23. COST EFFECTIVENESS FOR TURBINE RETROFIT MEASURES, 1977, FOUR-COUNTY AREA

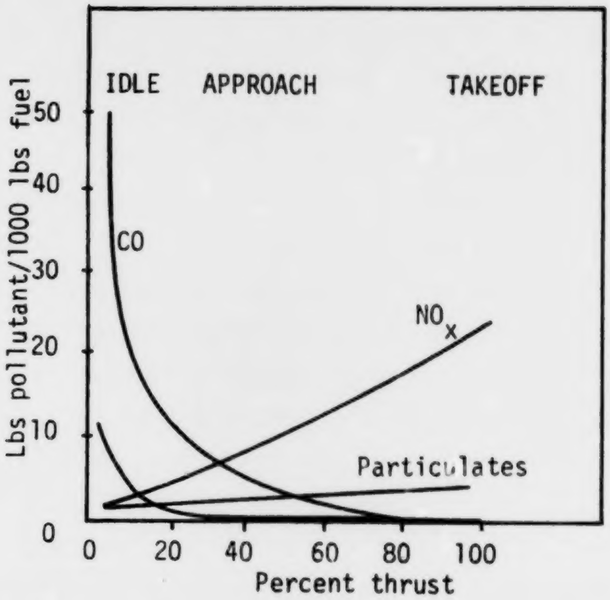
	Cost of Emission Control Per Ton of Pollutant Prevention			
Control Method	Particulates	SO_2	NO_x	THC
Major combustion chamber redesign	$4100	-	$5770	-
Fuel drainage control	-	-	-	$17000
Divided fuel supply	-	-	-	550
Water injection	-	-	$820	-
Compressor air bleed	-	-	-	550

1. Cost of air pollution control benefits are figured for Four-County Area only, and do not reflect the tons of emission reductions due to operation of the aircraft fleet in other areas.

- Modification of Ground Operations:

Aircraft ground operations contribute a substantial portion of the emissions of particulates, SO_2, and THC arising from overall aircraft operations. This is due to relatively high emission rates of the pollutants at low engine power levels, as well as the extended period of operation characteristic of idle-taxi modes for jet powered aircraft. A number of ground operation modifications have been proposed to reduce taxi-idle mode emissions. Regulations which may arise from these proposals have been deferred until operational and safety considerations can be studied jointly by the EPA and FAA. The procedures devised to control emissions by reducing the time of taxi-idle or by operating turbine engines at higher and more efficient thrust settings are shown in Table 3-24.

Modification of ground operations have been proposed primarily for reduction of HC and CO emissions. To this end, the most attractive option for ground control is the use of fewer engines at higher, more efficient power settings during taxi and idle modes. This conclusion is based on modal emission characteristics of turbine engines, typically protrayed as in Figure 3-5. At the elevated thrust required when only one engine is used during taxi and idle, the emission reduction is approximately 80% for HC during this mode. Since the idle mode accounts for a substantial portion of all turbine engine emissions, the introduction of this ground operation modification could reduce turbine aircraft hydrocarbon emissions by approximately 50% (see Table 3-24). However, introduction of the same ground operation modification will result in increases in particulate, SO_2 and NO_x emissions. Other options for ground operation controls, such as reducing the amount of time in the taxi and idle mode, would enable overall reductions in hydrocarbon emissions as well as particulate and NO_x emissions. The most effective overall option in this respect is the towing of aricraft to avoid taxi emissions.



Source: Reference [72],[73].

Figure 3-5. Gaseous Emission Characteristics of a JT8D Turbine Engine

Table 3-24 shows that towing of aircraft to avoid taxi emissions will reduce particulate and SO_2 emissions from turbine aircraft to 78% of the levels expected without controls. The projected emission reductions from the towing measure in the Four-County Area, and their cost, are shown in Tables 3-5, 3-6 and 3-7. The measure is most cost effective for preventing emissions of RHC and particulates. As an overall measure, it provides emission control of all pollutants for a cost of $79 per ton.

- Retrofits for Piston Aircraft:

The EPA has studied the technology which may be applied to reduce hydrocarbons and CO emissions from piston aircraft. Control methods considered feasible for aircraft piston engines include approaches that have been conceived or developed for automotive engines. Table 3-25 provides a summary of nine of the piston engine control methods identified by EPA as potentially feasible approaches. Recent research indicates that control method P1, fuel-

TABLE 3-24. COMPARATIVE REDUCTIONS RESULTING FROM CONTROL METHODS APPLIED AT LOS ANGELES INTERNATIONAL AIRPORT

Control Method	Resultant Emissions, % of Baseline Emissions			
	Particulates	NO_x	SO_2	THC
1. Increase engine idle speed	150	164	150	93
2. Increase idle speed and use minimal engines for taxi				
two engines	134	142	134	66
single engine	168	186	168	51
3. Eliminate delays at gate and runway	96	99	96	91
4. Transport passengers between terminal and aircraft	98	100	98	97
5. Tow aircraft to avoid taxi emissions	78	91	78	42
6. Avoid use of aircraft auxiliary power units (APU)	99	100	99	98.5

Calculations of emission reductions are based on 1) gaseous emission characteristics of JT8D turbine engine, 2) modal emission distributions, and 3) hydrocarbon reductions resulting from control methods at Los Angeles International Airport.

Source: Reference [4].

air ratio control, is the most technically feasible approach to substantial piston emission reductions. In this approach, leaner air-fuel ratios are obtained to produce reductions in hydrocarbons and CO. Figure 3-6 illustrates the effect of air-fuel ratio on piston emission characteristics. Operation at a 13 to 1 air-fuel ratio gives more than 50% reduction in CO and HC from levels at a 10 to 1 air-fuel ratio.

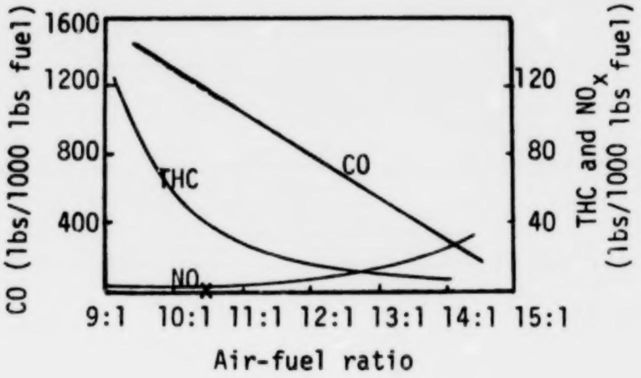


Figure 3-6. Emission Characteristics for Piston Engine

Source: Reference [73].

Because particulate and NO_x emission rates from piston aircraft are considered to be relatively low, the EPA has not been directly concerned with developing controls for these pollutant types. This is reflected in the aircraft emission standards, which are directed at control for hydrocarbon, CO and NO_x emissions only. Consequently, the available research data characterizing particulate emissions during various piston engine operating modes is quite limited.

Although particulate emissions associated with the candidate piston engine controls have not been specifically determined, it is expected that those controls which reduce exhaust hydrocarbon emissions will also produce particulate emission reductions. Experience with reciprocating automotive engines has shown that leaning air fuel ratios, currently the leading candidate measure for implementation as piston engine emission control, effects hydrocarbon emissions.

Currently, there are numerous uncertainties associated with the technical and economical feasibility of the various control methods as a retrofit measure. For control P1, it is suspected that engine detonation and overheating will occur with leaner air fuel mixtures in existing engines. Hence a redesign of the cylinder head for operation at the elevated temperatures would be required, and retrofits for measure P1 would be economically unfeasible. The FAA is

TABLE 3-25. ENGINE MODIFICATIONS FOR EMISSION CONTROL OF EXISTING AND FUTURE PISTON ENGINES

Control Method	Modification
Existing engines	
p1 - Fuel-air ratio control	Limiting rich fuel-air ratios to only those necessary for operational reliability
p2 - Simple air injection	Air injected at controlled rate into each engine exhaust port.
p3 - Thermal reactors	Air injection thermal reactor installed in place of, or downstream of, exhaust manifold.
p4 - Catalytic reactors for HC and CO control	Air injection catalytic reactor installed in exhaust system. Operation with lead-free or low-lead fuel required.
p5 - Direct-flame afterburner	Thermal reactor with injection of air and additional fuel installed in exhaust system.
p6 - Water injection	Water injected into intake manifold with simultaneous reduction in fuel rate to provide for cooler engine operation at leaner fuel-air ratios.
p7 - Positive crankcase ventilation	Current PCV system used with automotive engines applied to aircraft engines. Effective only in combination with one of preceding control methods.
p8 - Evaporative emission controls	A group of control methods used singly or in combination to reduce evaporative losses from the fuel system. Control methods commonly include charcoal absorbers and vapor traps in combination with relatively complex valving and fuel flow systems.
Future engines	
p9 - Engine redesign	Coordinated redesign of combustion chamber geometry, compression ratio, fuel distribution system, spark and valve timing, fuel-air ratio, and cylinder wall temperature to minimize emissions while maintaining operational reliability.

currently funding research by piston engine manufacturers (Continental/Lycoming) to study the feasibility of retrofitting piston engines for lower emissions with timing and fuel mixture ratio modifications. However, because of the apparent difficulties associated with the implementation of this measure, and because of its potential impact on aircraft emission reductions would be minor, it has not been included as a candidate control measure in the study.

3.2.5 Motor Vehicles

Emissions and Present Emissions Control

TABLE 3-26. ROLE OF MOTOR VEHICLE EMISSIONS IN ATMOSPHERIC POLLUTION OF FOUR-COUNTY AREA

	Percentage of Total Emissions in Four-County Area			
Year	Particulates	SO_2	NO_x	Reactive Hydrocarbons
1972	49	13	74	89
1977	35	11	51	85
1980	34	10	46	78

The important role of the motor vehicle in atmospheric pollution in The South Coast Four-County region is illustrated clearly above. With the Federal promulgation of air program implementation plans for the State of California, hydrocarbon and NO_x emissions from motor vehicles are expected to decline rapidly in the next few years. While the implementation programs do not address emissions of particulates and SO_2 directly, both these pollutant species will be affected by the control measure targeted for hydrocarbon and NO_x emission reductions. SO_2 emissions from light-duty vehicles will be reduced by about 7%, and light-duty vehicle and particulate emissions by 37%, by the year 1980. The measures principally responsible for these emission reductions will be non-leaded fuel utilization, in combination with the use of catalytic converter exhaust control devices. These measures are to be required under a retrofit program for all gasoline-powered, light duty motor vehicles of model years 1966 through 1974 capable of operating on unleaded gasoline having a research octane number of 91 or lower,[74]. These measures are also to be utilized in attaining 1975-76 motor vehicle emission standards for new light-duty vehicles. By 1980 it is estimated that 90% of all light duty vehicle VMT will be accumulated by vehicles equipped with the catalytic exhaust control device.

Extensive studies addressing the effects of catalytic converters on automotive exhaust emissions have been conducted by the EPA and by ESSO Research Corp.,[75]. These investigations employed measurement techniques for the determination of exhaust emissions which condense as sulfuric acid mist when emitted to the atmosphere. While only a trace of sulfuric acid is exhausted by conventional exhaust systems operating on leaded fuel, it was found that significant quantities of sulfuric acid aerosol are emitted from vehicles equipped with oxidation catalysts. The sulfuric acid emission rates increase markedly with increasing fuel sulfur content. It has also been found that, despite the alarming character change in particulate emissions (sulfuric acid mist), total particulates from the oxidizer devices are reduced from their former rate of .43 grams/mile.

The degradation of the reactive effectiveness of the catalyst, and the generation of sulfuric acid pollution from vehicle exhaust systems pose serious trade-off questions as to the suitability of the catalytic converter as an exhaust emission control. The EPA is currently committed to investigate the public health consequences of vehicles operating with catalytic converters, but as yet has not withdrawn 1975 interim Federal emission regulations which would necessitate catalytic devices to be installed on most new 1975 vehicles. Automobile manufacturers are currently scheduling installation of the catalytic converters in 1975 model year vehicles to meet these standards. EPA, in recent public hearings, has stated that sulfuric acid emissions will not become a serious problem until new cars with these devices comprise a larger segment of the vehicle popultaion. Reasonable concern over sulfuric acid emissions will be advisable, EPA recommends, in approximately two and one-half years, by which time it is presumed new technological developments will exist to resolve this problem. Of course it is apparent that this technology will be quickly overdue in the critical California Air Basins, where air quality implementation plans will insure that 65% of the light duty vehicle population be equipped with the oxidizing catalysts by 1977.

In addition to oxidizing catalyst retrofits, other significant mobile source control measures scheduled for implementation in the South Coast Air Basin include inspection-maintenance programs for light duty vehicles, a nitrogen oxides control retrofit, and emission standards for new motorcycles beginning in 1975. Each of these control measures contribute in part to the emission reductions expected for NO_x and hydrocarbons. However, their effect on particulate and SO_2 emissions is not considered to be significant.

Hydrocarbon and NO_x exhaust emission standards have also been established for heavy-duty gasoline powered vehicles, heavy-duty diesel powered vehicles, and motorcycles. The effect of the various motor vehicle standards in future years is reflected in the projected emissions summary of Figure 3-7. The rapid decrease in vehicular hydrocarbon and NO_x emissions is consistent with the objective of the promulgated air programs to reduce photochemical

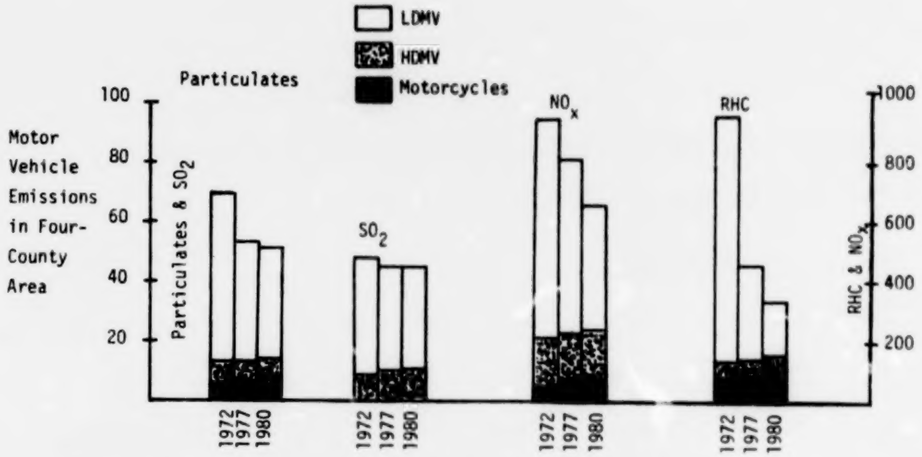


Figure 3-7 The Effect of Exhaust Emission Standards on Pollutant Emissions from Various Vehicle Categories

Source: Reference [4].

smog for the attainment of the ambient air standards for oxidant. This objective is not incompatible with the goal to reach the ambient standard for particulate matter. The role which vehicular emissions of NO_x and hydrocarbons assume as precursors in the formation of particulates will be effectively mitigated by the EPA strategies to reduce oxidant air pollution. However, the control of emissions of primary particulates has not been the target of these air programs, and the apparent benefit from the reduction of particulate emissions indirectly resulting from this strategy actually involves a serious trade-off pollution problem. This problem concerns the increased generation of sulfates already discussed above.

Except for the minor effects of certain transportation oriented constraints which would cause slight reductions in vehicle travel, the EPA implementation plans have no provisions which address the potential management of airborne particulate matter from vehicle tire wear. Unfortunately, tire wear accounts for a substantial portion of the particulate emissions caused by vehicle travel. In 1972, tire wear in the Four-County Area produced 15.2 tons/day of airborne particulates, or about 22% of the motor vehicle particulate pollution. By 1980, tire wear will be responsible for 18.6 tons/day of airborne particulate emissions, which amounts to 37% of the motor vehicle particulate pollution.

Alternative Control Options

The important options for control of motor vehicle particulate emissions are:

1. Modification of fuels
2. Particulate trap devices
3. SO_2 scrubbers
4. Fuel substitution
5. Tire options

- Fuel Composition - Lead Content:

Numerous studies have domonstrated the effect of fuel composition on particulate emissions from motor vehicles. Typically, it has been found that emission of particulate matter can be reduced with decreases in aeromatic, sulfur, or lead content in the fuel. The actual extent of these reductions depends on a number of variables, such as the driving test pattern, and the engine design, age, and condition.

Extensive testing has shown that approximately one-third of motor vehicle exhaust particulate matter is composed of lead. This lead discharge results directly from the lead content in the fuel. Tests show that stabilized unleaded-fuel cars emit about 40% less total particulates than the leaded fuel cars. Carbon represents about 70% of the total particulate matter when lead is absent in the fuel.

Current Federal regulations require that gasoline manufacturers shall provide non-leaded gasoline (maximum of .05 gm/gal) for use in automobiles by the year 1975,[76]. This rule was constructed to insure the use of fuels which would be compatible with catalyst exhaust controls which are projected for utilization in meeting the 1975 motor vehicle requirements. Hence in the next few years there will be a gradual change in the lead content of fuels on the market. Unleaded fuel will be available in increasing amounts to be consumed primarily by those vehicles equipped with catalytic oxidizers, and leaded fuels will be available in smaller volumes for use in the remaining vehicles. This trend will be particularly marked in the South Coast Air Basin, where the law calls for a catalytic oxidizer retrofit for all light duty vehicles of model year 1966 to 1974.

An important question in the large scale production of unleaded fuels is the effect this modification will have on the overall fuel composition, and consequently, on particulate emissions. (The techniques for producing the small proportion of unleaded fuels now on the market could be very different from a large volume production. Hence the unleaded fuels of tomorrow could be very different in composition from those used for exhaust emission tests today.) Lead addition to fuel is currently the most economic path to achieving higher octane numbers. If lead were to be removed from motor fuels, equivalent octane numbers would have to be provided by higher concentrations of more expensive blending components. Depending on the process utilized to achieve the octane rating, particulate emissions from vehicles may or may not be increased.

After lead addition, the next most economic way to raise the octane number of motor fuel is by increasing aeromatics content. To upgrade an existing "clean" regular motor fuel to its typical octane rating by addition of aeromatics rather than lead, the aeromatic content will typically be raised from 35% to 50%,[77],[78]. The effect of aeromatics content in unleaded gasoline on particulate exhaust emissions has been studied in several independent investigations. According to typical findings, [79], ther would be an increase in automobile particulate emissions of approximately 30% associated with the projected 35 to 50% aeromatics increase.

The impact of removing lead from motor fuels to overall fuel composition is lessened somewhat by the timely policy of automobile manufacturers to design 1971 and later model year cars to operate with 90-91 octane fuel. Previously the automobile companies manufactured engines with higher octane requirements, as reflected by leaded regular gasolines of 94-95 octane number which are produced to accommodate these engines. As the 1971 and later model year automobiles began to comprise the majority of the car popultaion, there will be a corresponding shift to lower octane motor fuel production by the refineries. The present average lead free pool gasoline will come close to satisfying the octane requirement for all production vehicles manufactured in the year 1971 and after, as well as those vehicles prior to 1971 able to operate on an ONR of 91,[80]. This observation, plus numerous other studies of the economics of lead removal, [78],[81],[82], has permitted the conclusion that a universally lead-free motor gasoline supply can be attained by 1977 without major dislocations in the petroleum refining industry, and without major changes in fuel composition.

Aside from the vehicles targeted for catalytic oxidizer installations, there will remain a significant portion of vehicles in 1977, and even 1980, which could potentially operate on leaded fuels. The impact of operating this vehicle segment on non-leaded fuels in terms of particulate emission reductions is shown in Table 3-28. The data show that total lead removal in fuels by 1977 will accomplish reductions of 28% of the motor vehicle exhaust particulate emissions in 1977, and 21% in 1980. This is based on the supported assumption,[82], that aeromatic content will not increase appreciably in the unleaded transition.

The cost of producing unleaded fuels depends heavily on restrictions limiting the aeromatic content. If aeromatic content can be varied to produce desired octane ratings in the unleaded fuels, costs would be minimal. Moreover, since lower octane fuels will be permissible in future motor fuels, unleaded fuels will not require substantial increases in aeromatic content.

TABLE 3-28. THE EFFECT OF LEAD REMOVAL IN MOTOR FUELS ON MOTOR VEHICLE PARTICULATE EXHAUST EMISSIONS IN FOUR-COUNTY AREA

	Projected Baseline Particulate Emissions Tons/Day		Particulate Emissions Reductions[a] Tons/Day	
Motor Vehicle Category	1977	1980	1977	1980
Light duty	40.4	35.8	4.4	1.4
Heavy duty	6.6	7.1	2.6	2.8
Motorcycles and other miscellaneous vehicles	7.0	7.7	2.8	3.1

[a] Emission reductions are based on 40% decrease attributable to all vehicles not equipped with catalytic oxidizers when operating on unleaded fuel. It was assumed that aeromatic content of fuel was essentially unchanged. The portion of light duty vehicle VMT for those vehicles equipped with catalytic oxidizer exhaust control was taken as 73% in 1977, and 90% in 1980,[2].

It is significant to the economics of unleaded fuel, that vehicle exhaust from a catalytic muffler shows little sensitivity to aeromatic fuel content. Particulate emissions from the catalytic oxidizers are typically composed of almost 100% sulfates and water, with very minor traces of carbonaceous particles present. Increased aeromatics are expected to affect gaseous hydrocarbon emissions significantly, since organics are essentially eliminated by the purposeful behavior of the oxidizing catalyst. These observations would suggest an arrangement of the vehicle gasoline pool in which higher content aeromatics would be used to obtain octane levels for vehicles equipped with catalytic mufflers, while low content aeromatic fuel would be provided for vehicles operating without the catalytic exhaust device. This motor fuel configuration might provide a more economic path to octane attainment, by permitting a higher overall aeromatic composition in the motor gasoline pool.

Another significant consideration in unleaded fuel economics are the tradeoff benefits due to vehicle maintenance savings. These savings are due principally to longer spark plug life, less oil contamination, and greater exhaust system life,[78],[81].

Considering the above observations, it is apparent that the cost of the control option, complete removal of lead in fuels, can be implemented at less than the published estimates,[78], of .1¢ per gallon of gas. This amounts to a cost of $475 per ton of particulate emissions controlled (Table 3-5).

- Fuel Composition - Sulfur Content:

  New attention is now being drawn to the role of sulfur in motor vehicle emissions. This is because it has been shown that vehicles equipped with oxidation catalysts convert a substantial portion of the sulfur in the gasoline to sulfuric acid particles. The emission of sulfuric acid vapors directly into the atmosphere as high concentration sources near transportation corridors poses an important new health problem.

  An obvious means of preventing emissions of sulfuric acid from catalytic oxidizer equipped vehicles, or SO_2 from all vehicles, is to remove the sulfur from the fuel. Desulfurization of automotive gasolines can be accomplished with facilities similar to those now employed to desulfurize low sulfur fuel blend stocks for fuel oil supply to electric utilities companies. However, in most installations, the operating severity of the equipment cannot be sufficiently increased for sulfur contents less than about .05%, hence, it is necessary to construct new facilities for more complete desulfurization. In one process which has proven effective for essentially complete desulfurization, the Chevron Isomax, a wide range of distillites, from diesel up to 1100°F end point vacuum gas oil, are economically processed to sulfur contents less than 100 ppm. Several oil companies are now licensed to use the Isomax process. Because of its relatively widespread recognition in the literature, it has been considered here as candidate equipment for implementing desulfurization control.

The impact of automotive fuel desulfurization to levels below 100 ppm on motor vehicle emissions is shown in Table 3-29. Desulfurization of the entire spectrum of vehicle motor fuels to less than 100 ppm sulfur content would result in particulate emission reductions of about 87% for vehicles equipped with the catalytic mufflers. Sulfuric acid emitted from these vehicles would be reduced by about 99%. Prevention of SO_2 emissions would vary from 25 to 60% depending on the vehicle category and the type of fuel.

TABLE 3-29. THE EFFECT OF AUTOMOTIVE FUEL DESULFURIZATION (100 ppm) ON MOTOR VEHICLE EMISSIONS IN FOUR-COUNTY AREA

	Projected Baseline Emissions Tons/Day		Emissions Reductions Tons/Day	
Motor Vehicle Category	1977	1980	1977	1980
PARTICULATES				
Light duty	40.4	35.8	15.5	19.8
SULFUR DIOXIDE				
Light duty				
with catalyst	18.2	22.5	10.8	13.4
without catalyst	17.4	13.2	14.8	11.2
Heavy duty				
diesel	9.7	10.4	9.2	9.9
gasoline	.8	.9	.7	.8
Motorcycles & off-road vehicles	-	-	-	-
TOTAL (SO_2)	46.1	47.0	35.5	35.3

1. The portion of light duty VMT for vehicles equipped with catalytic mufflers was taken as 73% in 1977, and 90% in 1980,[2].
2. SO_2 reductions are based on 85% reduction in gasoline sulfur content, and 95% in diesel fuel. For light duty vehicles equipped with catalytic mufflers it was assumed that 30% of the fuel sulfur is converted to sulfate (sulfuric acid) and the remainder is emitted as SO_2.

Source: Reference [4].

The economics of motor vehicle emission control via the desulfurization route is portrayed in Table 3-30. The measure of desulfurization is most cost effective as a control for SO_2 emissions. Taken as a joint control for emissions of particulates and SO_2 combined, the cost effectiveness is substantially enhanced. Moreover it is also evident that desulfurization facilities utilized in an effort to prevent motor vehicle emissions are also integral to control efforts to prevent emissions from combustion equipment and refinery process equipment operational in the Four-County Area. The various desulfurization schemes which have been examined as candidate emission control measures for a given targeted process (combustion, motor vehicles, refineries, aircraft) in this study, cannot be viewed as mutually exclusive measures. There is substantial overlap in the equipment requirements for the various desulfurization options identified in this study, and therefore the cost effectiveness of any of these measures analyzed independently of its side benefits does not provide a true credit of effectiveness.

TABLE 3-30. COST OF DESULFURIZATION OF VEHICLE FUELS FOR CONTROL OF EXHAUST EMISSIONS

Equipment	Capital Cost	Annual Operation Cost Increase	Total Annualized Cost	Cost Per Ton of Emission Prevented			
	in Millions of Dollars			Particulates		SO_2	
				1977	1980	1977	1980
Desulfurization facilities (8 VGO high severity Isomax units of avg. capacity, 40,000 barrels/day)	80	13.8	21.8	\$3850	\$3120	\$1680	\$1690

Source: Reference [4].

- Particulate Trap Devices:

Several systems for removing particulate matter from exhaust gases have been under evaluation. These devices have typically been designed to manage particulate matter from vehicles with standard exhaust systems (without the oxidizing catalyst), principally as a trap for lead particulate. None of the systems tested to date have clearly demonstrated an effectiveness which would allow use of leaded gasoline with catalytic converters. The most extensive testing and development of particulate traps has been performed by Ethyl Corporation. The results of these efforts have provided particulate trapping systems which are effective as retrofit emission controls for incomplete control for lead emissions when employed in new vehicles.

Most of the proposed particulate traps consist of an agglomerator, an inertial separator, and a filter. The agglomerator unit is generally composed of beads or mesh, and provides a surface for mechanically agglomerating the particles into larger sizes. The inertial separator is generally a cyclone or combination of cyclones used to spin out the particles at high velocity into a reservoir. A filter is often employed at the exit of the trapping unit to remove smaller particles remaining in the gas stream when exiting from the cyclone.

Preliminary data of commercial prototype retrofits units developed by Ethyl Corporation have shown that total particulate emissions in standard exhaust systems may be reduced by 70% with traps consisting of agglomeration and inertial reactions. Lead is reduced by more than 90%,[79],[83]. More sophisticated traps now being developed by Ethyl have shown ability to remove nearly all (95%) lead and particulate emissions in the standard exhaust system,[84]. These higher efficiency systems are not engineered as retrofit units and have limited adaptability to in-use vehicles. They are intended for adaption to new vehicle designs whenever the vehicle is equipped with a conventional exhaust system. Since the traps are essentially mechanical collectors by nature, they are therefore ineffective as a control for vapors of sulfuric acid. Particulate traps for sulfuric acid vapors have been developed to a limited extent. The technology on sulfuric acid removal is discussed in the next section (SO_2 Scrubbers).

There is currently substantial indication that very effective particulate trapping systems can be engineered and adapted to control exhaust emissions from both in-use and new motor vehicles which utilize standard exhaust systems. This indication is based on the apparent effectiveness of preliminary particulate trapping devices which have been constructed with limited budgets and within a very limited segment of the industry. A more substantial effort, supported by greater certainty of the market for the trapping devices, would undoubtedly produce significant gains in effectiveness and costs over the existing control devices. It appears feasible that production of these units could be accomplished by 1977.

The preventions of particulate emissions when motor vehicles are equipped with particulate traps is shown in Table 3-31. While particulate traps are not applicable to a major segment of the vehicle population (65% of light duty vehicles in 1977 and 90% in 1980), their installation on the remaining vehicle population can effect a 46% particulate emission prevention in 1977, and 35% in 1980.

TABLE 3-31. IMPACT OF PARTICULATE TRAPS ON PARTICULATE EMISSIONS FROM MOTOR VEHICLES IN FOUR-COUNTY AREA

Motor Vehicle Category	Projected Baseline Particulate Emissions Tons/Day 1977	Projected Baseline Particulate Emissions Tons/Day 1980	Prevention of Particulate Emissions Tons/Day 1977	Prevention of Particulate Emissions Tons/Day 1980
Light duty				
with catalyst	20.2	25.8	0	0
without catalyst	20.2	10.0	16.2	8.0
Heavy duty	6.6	7.1	5.3	5.7
Motorcycles and off-road vehicles	7.0	7.7	3.5	3.9
TOTAL	54.0	50.6	25.0	17.6

Notes:

1. It was assumed that vehicles non-equipped with catalysts would utilize leaded fuels, and that leaded fuels would be available through 1980.
2. Trap devices were assumed to be 80% efficient.

Due to the very limited operating data available the economics of particulate traps are not well defined. Ethyl estimates they would be able to provide a trap with about 80% collection efficiency for the light duty vehicle at a cost of $14,[83]. The device would be incorporated into a muffler, and would be rated for a lifetime of 36,000 miles, with no periodic maintenance required. This amounts to a cost of approximately .03¢ per mile per vehicle. Table 3-5 summarizes the overall economics of an implementation measure to equip the Four-County Area with motor vehicle particulate traps.

. SO_2 Scrubber Particulate Trap:

Because the important discovery of the interaction of sulfur and oxidizing catalysts is relatively recent, and because of the uncertainty associated with the implementation of the catalytic control device, limited effort has been directed toward development of auxiliary hardware to circumvent the problem that sulfur poses for the catalytic controls. Perhaps the most promising equipment which has been developed to be responsive to the sulfur-catalyst problem is the molten carbonate scrubber-mufflers by Atomics International. Designed principally to remove lead vapors in the heated portion of the exhaust upstream of the catalytic converter, road tests have shown the scrubber also removes essentially all the sulfur oxides in the exhaust,[85]. The unit operates on the basis that lead and sulfur compounds in vehicle exhaust are acidic and will react chemically with alkaline molten carbonate. In these reactions, lead vapor is converted to solid lead carbonates and oxides, and sulfur dioxide is reacted to metal sulfates.

The scrubber-muffler device utilizes heat from the engine exhaust in attaining the 750°F melting point of the molten carbonate mixture rapidly. The molten mixture is aspirated out a venturi suction tube into the gas stream to facilitate rapid acid-base reactions. The resulting carbonates and sulfates are retained by absorption on the mesh. Particulates are wetted and retained in the carbonate mixture. Test data,[86], show the collection efficiency for particulates in the scrubber is about 90%, making the device both an effective particulate and SO_2 control for vehicles not equipped with the catalytic converter.

The preventions of SO_2 and particulate emissions when motor vehicles are equipped with the Atomics International scrubber-muffler system are shown in Table 3-32. Because of the very effective control of SO_2 and particulates claimed by Atomics International,

TABLE 3-32. IMPACT OF SCRUBBER ON SO_2 AND PARTICULATE EMISSIONS FROM MOTOR VEHICLES IN FOUR-COUNTY AREA

Motor Vehicle Category	Projected Baseline Emissions Tons/Day 1977	Projected Baseline Emissions Tons/Day 1980	Emission Preventions Tons/Day 1977	Emission Preventions Tons/Day 1980
PARTICULATES				
Light Duty				
with catalyst	20.2	25.8	18.1	23.2
without catalyst	20.2	10.0	17.2	8.5
Heavy Duty	6.6	7.1	5.6	6.0
Motorcycles and off-road vehicles	7.0	7.7	5.9	6.6
TOTAL	54.0	50.6	46.8	44.3
SULFUR DIOXIDE				
Light Duty	35.6	35.7	33.8	33.9
Heavy Duty	10.5	11.3	10.0	10.7
Motorcycles and off-road vehicles	-	-	-	-
TOTAL	46.1	47.0	43.8	44.6

Notes:

1. The scrubber was assumed to have an efficiency of 95% for SO_2 removal and 85% for particulate collection.
2. Since the scrubber removes SO_2 upstream of the catalytic oxidizer, conversions of SO_2 to sulfuric acid particulates does not occur. Particulates of other types are also removed by the scrubber. Hence it is assumed that particulate emissions from vehicles with the catalytic oxidizer will be controlled to 90% efficiency.
3. It was assumed that the scrubber-muffler unit could be adapted for retrofit on motorcycles and heavy duty vehicles,[87].

the overall emission control impact on the motor vehicle population is impressive. Serious reservation should probably be maintained relative to this preliminary analyses until further testing can be accomplished to confirm the very encouraging preliminary data.

The cost to the consumer for the scrubber and muffler device has been estimated at $35 for a factory installed device to $45 for retrofit units. This compares to a typical muffler purchase and installation cost of approximately $22. Maintenance of the scrubber device consists of replacing the salt solution every 15,000 to 20,000 miles at a cost of $10, [85]. The live of the dual function scrubber and muffler is estimated at 50,000 miles.

The overall economics of implementing the installation of scrubber devices on the motor vehicle population as a pollution control measure is summarized in Table 3-5 and 3-6. Because the unit has nearly equal effectiveness either as a particulate trap or for SO_2 removal, it is applicable as an emission control for all the motor vehicle **categories**, whether they are equipped with catalytic oxidizers or not. Clearly the device is more cost effective for those vehicles not equipped with the device since more emissions would be prevented from these sources for an equivalent cost. Similarly, the scrubber would be most cost effective for heavy duty vehicles from which the greatest potential of emission preventions exists.

3.2.6 Organic Solvents

Emissions and Existing Controls

Most of the emissions originating from the use or manufacture of organic solvents occur from the process of natural or forced evaporation. For example, when architectural coatings are applied with solvents, the solvents evaporate into the atmosphere as the coating forms a film. In dry cleaning operation of clothes, the solvents are removed by heat, or forced evaporation. In general, the emissions from these activities are hydrocarbon vapors, of varying reactivity depending on the nature of the solvents used. With the Federal promulgation of air program implementation plans for the State of California, release of solvent vapors to the atmosphere will be prevented by stricter emission controls for dry cleaning and degreasing operations. The user of solvents in those operations may choose to comply with the regulation by applying emission control hardware, or by selection of a non-photochemically active solvent.

The Federal emission controls are directed at attaining the oxidant ambient air standards, and therefore control stipulations for the use of organic solvents address the prevention of reactive hydrocarbons. The scheduled controls do not significantly affect particulate emissions, as can be seen in Table 3-5. There are essentially no SO_2 or NO_x emissions yielded by organic solvent operations.

A characterization of the various emission sources resulting from the use of organic solvents in Los Angeles County revealed that painting operations in spray booths account for an overwhelming portion (85%) of their particulate emissions. This is due to the fact that emissions from other organic solvent operations are controlled with higher collection efficiency, while emissions from spray booths are typically controlled to low efficiencies. The average emission level from a typical paint spray booth is relatively small, such that in the majority of cases Rule 66, which limits total discharge of organic materials from a given piece of equipment to less than 15 pounds of organic materials per day, is not violated. In addition, the emissions are well diluted, so as to comply with Rule 52 (which limits the concentration of particulate matter arising from a source according to the volume discharge) and Rules 50 and 51 (visible emissions and nuisance rules). Table 3-33 summarizes clearly the important role that paint spraying operations play in atmospheric pollution from organic solvent emission sources in the Four-County Area.

TABLE 3-33. EMISSIONS FROM PAINT SPRAY BOOTHS AND "OTHER" ORGANIC SOLVENT OPERATIONS, FOUR-COUNTY AREA, 1972

Operation	No. of Permits	Particulate Emissions Tons/Day Actual	Particulate Emissions Tons/Day Preventions	Efficiency of Control
Paint spraying in spray booth	4482	6.8	1.1	13.5%
"Other"	3470	1.2	2.8	70.8%
TOTAL	7952	8.0	3.9	32.8%

Source: Reference [4].

There are basically three types of devices used to capture the paint spray of paint spray booths before the ventilation fan exhausts the booth air to the atmosphere. They are: 1) dry baffle plates, 2) arrestors or filters, 3) a water wash. Baffle plates capture paint spray particles with low efficiency, and are generally used as the most economic route for protection of the spray booth operator and prevention of nuisance emissions. Arrestors or filter paper provide collection of paint particles with efficiencies up to 98%. Where filters are not practical for continuous painting operations, water washes may be used with collection efficiencies of 95%.

Additional Control Options

Since paint spraying in spray booths accounts for 85% of all emissions from organic solvent activities, it follows that it shall be the target for additional controls. Consultation with spray booth manufacturers revealed the most frequently used spray booth is about 12 feet wide by 7 feet high at the venting entry, and is usually equipped with a dry baffle collector. It was estimated that 80% of the booths in Los Angeles are of this general description,[88]. To improve the efficiency of the 4482 spray booths operating with county permits, two retrofits are feasible: an arrestor filter mat, or a water wash. In many instances the water wash is the more economic route as servicing requirements are very minimal, while filters must be replaced regularly when utilized under continuous spray operations.

The emission preventions obtained by retrofitting the present population of paint spray booths in the Four-County Area with a water wash is shown in Table 3-5. This control measure can yield a 77% overall prevention of particulate emissions arising from organic solvent usage. Based on an average retrofit cost of $2800 per spray booth, annualized to $280 per year at 10% interest, the total annualized cost for the entire population of retrofits is $1.6 million. This amounts to a cost effectiveness of $724 per ton of particulate emissions removed from the atmosphere.

3.2.7 Metallurgical Processes

Emissions

The principal emissions produced during metallurgical operations are particulates and SO_2. These emissions are generated from the melting of metals and ores in furnaces. As the feed in the furnace is melted, combustibles such as grease, oil and burner fuel are burned and emitted along with refining emissions which consist of oxide fumes of the metal constituents in the furnace melt mixture. The quantities of emissions generated by furnace operation depends mainly on the specific melting process. The total emissions deriving from activity of all metallurgical furnaces in the Four County Area is tabulated in Table 3-5, 3-6 and 3-7. Emissions from incomplete combustion constitute a small portion of the furnace effluents, as can be seen by the relatively minor quantities of NO_x generated.

Emission Controls

Substantial effort has already been employed throughout the metallurgical industry to achieve a high rate of particulate collection efficiency. The basic control equipment generally consists of either a baghouse or an electrical precipitator. A critical aspect of the successful control of furnace dust and fumes is the hooding design. Various hooding configurations are employed depending on the layout and shape of the furnace, and the volume of effluent to be managed. The most difficult design problem concerns the provision of adjustability for the hood to facilitate furnace charging and access. For the hood to remain effective it must be positioned to allow continuous capture of emissions arising during the charging process.

It is estimated by the Los Angeles Air Pollution Control District that about 92% of all particulate emissions generated from metallurgical operations are prevented from entering the atmosphere,[89]. However, with regard to emissions of SO_2, there are virtually no controls applied. SO_2 emissions arise almost solely from lead refining, in which a substantial amount of sulfur is present in various forms in the charge to the furnace. The melting of the charge oxidizes the sulfur compounds resulting in emission of SO_2.

There are a vast number of furnaces utilized in which no emission control system has been incorporated. These furnaces are relatively small, and the effluents which are diluted and discharged to the atmosphere by the hooding capture systems do not constitute a violation of air pollution regulations. Nevertheless, these "uncontrolled" emissions account for 58% of the air pollution from all metallurgy operations. Table 3-34 provides a characterization of these small furnaces and their role in emissions from metallurgical operations.

TABLE 3-34. CHARACTERIZATION OF FURNACE CONTROL EFFECTIVENESS, FOUR-COUNTY AREA, 1972

Type of Furnace Control	No. of Permits	Particulates Emitted from Control System	Particulates Prevented from Emitting	Control Efficiency
None	1782	7.2	0	0
Baghouse	483	4.7	128	96.4
Precipitator, Scrubbers, & Afterburners	224	1.4	3.9	90.7
TOTALS	2489	12.3	132	91.5

Source: Reference [4].

Additional Control Options

There are probably very few basic equipment modifications which would enable significant improvements in particulate collection efficiencies for those furnaces equipped with control systems. However it has been found that baghouses have on numerous occasions been inadequately maintained, resulting in poor collection efficiencies (less than 90%),[90],[91]. Baghouse filters must be designed to be compatible with the effluent gas temperatures, and condensation should be avoided or filters will saturate, causing increased pressure drop and exhaust air flow. Bags must be shaken regularly as furnace fumes tend to agglomerate on the fibers. It is conceivable that significant performance improvements could be affected in furnace emission control systems if stricter industrial maintenance practices were implemented. However, it would be extremely difficult to assess the benefits of such a program without extensive inventigations of prevailing emission rates and maintenance procedures. It is noted however, that the APCD emission inventory file credits baghouse installations with a composite control effectiveness of 96.4% (this is based on estimates derived, for the most part, from theoretical calculations, and not field measurements), which, it would seem, already presumes a high degree of maintenance consciousness.

The vast number of furnaces which currently are not equipped with emission control devices can be best retrofitted with baghouse installations in most instances. Baghouse operating temperature is an important consideration, and often temperature control must be provided for by installing extra equipment such as convection cooling columns, or thermal insulation.

Lead melting operations are presently equipped with baghouse emission control systems, but this equipment has no substantial effect on SO_2 pollution. Several candidate SO_2 removal processes may be employed at the baghouse effluent to obtain preventions of SO_2 emissions by 90%. These controls have been discussed in Section 3.1.

The air pollution control benefits of retrofitting baghouse control systems to furnaces which currently are vented directly to the atmosphere are shown in Table 3-5. The retrofit measure will provide a 56% reduction in total particulate matter emitted by metallurgical melting operations. The impact of retrofitting lead processing furnaces with SO_2 cleanup systems is shown in Table 3-6. The add-on SO_2 removal systems require pretreatment of the effluent for particulate removal, hence they must be sized to manage the effluent of the baghouses. In furnace emission control applications, the baghouse effluent volumes are often several times that of the furnace itself due to the dilution air used to cool the hot fumes and prevent condensation or rapid agglomeration of matter on the baghouse filter fabric. Based on numerous studies now being carried out to assess the performance of SO_2 cleanup systems, it is estimated that 90% of the SO_2 pollution generated by metallurgical activities can be eliminated.

The cost of retrofitting uncontrolled pollutant emissions of SO_2 and particulates from melting furnaces in the Four-County Area, is shown in Tables 3-5 and 3-6. Several assumptions were necessary in the derivation of the cost figures, and the estimates are preliminary at best. However, the magnitude of the cost effectiveness closely parallels the cost of other similar pollution control systems which are well documented in the literature, and in other sections of this report. Treatment for SO_2 removal from the effluent of lead melting furnaces is about ten times more cost effective than particulate collection from the small uncontrolled furnaces scattered about the Four-County Area.

3.2.8 Chemical Processing Industry

Emissions

The principal emissions arising from chemical processing activities are particulates and SO_2 (see Tables 3-5, 3-6, and 3-7). In future years the chemical industry is projected to be responsible for about 4% of all particulate emissions, and only 2% of the SO_2 emission inventory. Emissions of SO_2 are expected to be reduced dramatically by 1977 owing to the impact of Rule 53.2 of the Los Angeles Air Pollution Control District. Rule 53.2 will provide for reduction of SO_2 emissions from the vent gas of sulfur recovery plants. SO_2 removal processes are presently being applied in Los Angeles to reduce these emissions below 500 ppm.

Emission Controls

From the detailed itemization of emission sources and emission control equipment contained in Support Document #4, [4], it is apparent that appreciable effort has already been invested to achieve a high rate of particulate collection efficiency. Particulate control devices being used consist of mechanical collectors, wet scrubbers, electrostatic precipitators, filters, and incinerators. The Los Angeles Air Pollution Control District estimates that about 97% of all particulate emissions generated by chemical processing operations are prevented from entering the atmosphere.

The principal source of SO_2 emissions from the chemical industry are sulfur recovery plants which process the offstream acid gases at oil refineries. The acid gases are processed by the recovery plants to obtain sulfur and vent gases. Previously these vent gases were incinerated and discharged through a stack to the atmosphere. The concentration of SO_2 in these stack gases varied between 2000 and 20,000 ppm. The SO_2 from the stacks of these plants are now being controlled by new available technology (see Section 3.1) to a stack discharge concentration of less than 500 ppm. SO_2 removal processes have now been applied successfully to most recovery plants in Los Angeles, but in some instances inadequate control systems were initially installed, causing delays in the compliance schedule. Scheduled equipment replacements or improvements will insure compliance before 1977.

Alternative Controls

A substantial degree of control (reflecting the best available technology) has been accomplished over particulate emissions from the chemical industry in Los Angeles County. It is presumed (in the absence of suitable data for confirmation) that a similar level of particulate emission control has been accomplished throughout the remainder of the Four County Area, since the process emission regulations are fairly consistent for the various counties. With respect to the emissions of SO_2 the newly adopted regulations for sulfur recovery plants are especially stringent, requiring commitment of oil refineries to utilization of expensive control equipment still in its infant stages of development. These controls are to be implemented throughout Los Angeles County, which contains all sulfur recovery plants within the Four County Area. Owing to the impact of SO_2 and particulate regulations in the Four County Area, it would not appear that significant additional emission reductions can presently be achieved with reasonable available technology. Hence, no alternative control measures have been identified for the chemical processing industry.

4.0 EVALUATION OF ALTERNATIVE CONTROL STRATEGY SCENARIOS

This chapter presents and evaluates alternative control strategy scenarios for reducing suspended particulate levels in the Los Angeles Region. Each control strategy is composed of a specific combination of the control measures which were described in Chapter 3. For each strategy, the total reduction in primary particulate, SO_2, NO_x, and RHC emissions is calculated. Then, these emission reductions are translated into air quality impacts. A brief evaluation is also made of the control costs and implementation problems associated with each strategy.

Four different control strategies are examined below. Section 4.1 describes a reasonable/implementable scenario that emphasizes fuel desulfurization. Section 4.2 deals with a scenario based on maximal technological control by 1977. Section 4.3 discusses a delayed strategy based on methanol conversion; this strategy has a slow time table but results in low emissions by 1980. None of the above strategies will attain the primary national standard at all monitoring sites. To attain the standard, significant reductions in growth and vehicle use as well as industry relocation appear necessary. Section 4.4 describes the very drastic strategy that would be required to actually attain the federal air quality standards for particulates in the Los Angeles Region.

4.1 CONTROL STRATEGY I: A REASONABLE/IMPLEMENTABLE SCENARIO FOR 1977 AND 1980

This section presents and evaluates the first of four alternative control strategies to be examined in this study. Control Strategy I is called the "reasonable/implementable" scenario. It is reasonable since it avoids duplication in controls and emphasizes the most cost-effective measures. Further, it relies on a general policy of desulfurization which has the advantage of reducing several source types simultaneously, (e.g., refineries, power plants, automobiles, diesels, etc.). In fact, an alternative name for Control Strategy I would be the "desulfurization" scenario.

Control Strategy I is implementable in a relative sense. Although there are considerable implementation obstacles to be overcome in this first strategy, there are even greater problems with the three strategies to be examined later. Implementation, enforcement, and administrative difficulties will be significant for any strategy which can bring about substantial improvements in particulate air quality for the Los Angeles Region.

The control measures which make up Control Strategy I are listed on the left side of Table 4-1. Detailed descriptions of these measures can be found in Chapter 3 of this report or in Support Document #4. As with all the control strategies proposed here, Control Strategy I assumes that the EPA oxidant plan will be implemented.* This assumption is intended as a recommendation of that plan. The EPA RHC/oxidant control program is very important for reducing secondary organic particulates as well as for controlling oxidant.

4.1.1 Impact on Emission Levels

The right hand side of Table 4-1 presents the emission reductions to be expected from Control Strategy I in 1977 and 1980. As can be seen in Table 4-1, the largest particulate reductions occur in the stationary fuel combustion category (high efficiency electrostatic precipitators or

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* See Table 3-8 for a description of the EPA oxidant plan.

TABLE 4-1. CONTROL STRATEGY I - REASONABLE/IMPLEMENTABLE STRATEGY FOR 1977 and 1980

Note: The EPA Oxidant Implementation Plan is Assumed as Part of this Strategy

Source Category	Proposed Control Measures for Strategy I	Emission Reductions (tons/day)							
		1977				1980			
		Susp. Part.	SO_2	NO_x	RHC	Susp. Part.	SO_2	NO_x	RHC
A. Petroleum Industry	A.1 Improve efficiency of regenerator unit dust control systems from 95% to 99% (by upgrading precipitators)	2	---	---	---	2	---	---	---
	A.2 Desulfurization (to .05% S) of all petroleum feed to catalytic crackers	---	51	---	---	---	51	---	---
B. Stationary Fuel Combustion	B.1 High efficiency electrostatic precipitators or high efficiency baghouses applied to power plant boilers, large non-power plant boilers, and refinery heaters (includes effect of B.2 below)	67	---	---	---	64	---	---	---
	B.2 Desulfurization of fuel oils to 0.5% S with new desulfurization technology (applied to power plant boilers and large non-power plant boilers)	---	168	---	---	---	308	---	---
	B.3 SO_2 stack gas removal systems on all refinery heaters	---	33	---	---	---	34	---	---
	B.4 Low excess air firing and flue gas recirculation for small power plant boilers and on large/medium size non-power plant boilers	---	---	242	---	---	---	227	---
	B.5 Low excess air firing for refinery heaters	---	---	26	---	---	---	24	---
	B.6 Water injection or exhaust gas recirculation for stationary internal combustion engines	---	---	66	---	---	---	62	---
C. Organic Solvent Use	C.1 Water wash equipment for all paint spray booths	6	---	---	---	6	---	---	---
D. Metallurgical Processes	D.1 Baghouses for furnaces with uncontrolled particulate emissions	8	---	---	---	8	---	---	---
	D.2 SO_2 removal systems for all furnace effluent stacks	---	14	---	---	---	14	---	---
E. Chemical Industry		---	---	---	---	---	---	---	---
F. Minerals Industry		---	---	---	---	---	---	---	---
G. Motor Vehicles	G.1 Desulfurization of motor fuels to 100 PPM sulfur content	13	36	---	---	17	35	---	---
	G.2 Particulate traps for motor vehicles without catalytic mufflers	21	---	---	---	15	---	---	---
H. Aircraft Operations	H.1 Modification of ground operations: towing of aircraft to avoid taxi-idle emissions (only after landing). Also, water injection for jet engines.	2	1	15	6	3	1	22	8
Total Emission Reductions for Control Strategy I		119	303	349	6	115	443	335	8

baghouses) and the motor vehicle category (desulfurization of motor fuels and particulate traps for vehicles without catalytic mufflers). The most significant control of SO_2 is achieved by a major desulfurization program, (for catalytic cracker feed, fuel oils, and motor fuels). Significant NO_x reductions are obtained through a control program for stationary NO_x emission sources.

The emission reductions in Table 4-1 are to be subtracted from the emission projections for the EPA oxidant plan which is included as part of the strategy. Table 4-2 gives the projected emissions for the 4-County Area after application of Control Strategy I. It is noteworthy

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TABLE 4-2

EMISSION PROJECTIONS FROM CONTROL STRATEGY I
FOR THE 4 COUNTY SUB-AREA

		PRIMARY SUSPENDED PARTICULATES			NITROGEN OXIDES		
		1972	1977	1980	1972	1977	1980
EMISSION PROJECTIONS UNDER EPA OXIDANT PLAN	(tons/day)	178	223	233	1345	1614	1434
EMISSIONS RESULTING FROM CONTROL STRATEGY I	(tons/day)		104	118		1266	1100
	(% of 1972)		58%	66%		94%	82%

		SULFUR DIOXIDE			REACTIVE HYDROCARBONS		
		1972	1977	1980	1972	1977	1980
EMISSION PROJECTIONS UNDER EPA OXIDANT PLAN	(tons/day)	444	524	535	1095	547	410
EMISSIONS RESULTING FROM CONTROL STRATEGY I	(tons/day)		221	92		541	402
	(% of 1972)		50%	21%		49%	37%

that the control strategy produces reductions in each emission category from the 1972 base emission level. Very significant decreases in primary particulates, RHC, and especially SO_2 are obtained.

As noted in Section 2.3, the air quality/emission level model is applied to the Chino monitoring site in a specialized way. For that location, estimates are required of particulate and SO_2 emission reductions from the localized source, (Kaiser/Edison complex). Table 4-3 presents the expected reductions for the Kaiser/Edison complex under Control Strategy I, (see Appendix A of Support Document #3 for the calculation method). As illustrated by Table 4-3, the controls on metallurgical processes, industrial fuel combustion, and power plant fuel combustion produce significant reductions in suspended particulate and SO_2 emissions from the Kaiser/Edison complex.

TABLE 4-3

PRIMARY PARTICULATE AND SO_2 EMISSION ESTIMATES FOR THE KAISER/EDISON COMPLEX IN THE WESTERN SAN BERNARDINO COUNTY HOT-SPOT UNDER CONTROL STRATEGY I

	EMISSIONS (% of 1972 LEVEL)	
	1977	1980
PRIMARY PARTICULATES	32%	34%
SO_2	54%	16%

4.1.2 Air Quality Impact

The emission projections for Control Strategy I have been translated into air quality projections using the air quality model developed in Section 2.3. The results for eight locations in the 4 County Sub-Area are presented in Figure 4-1. It is evident that significant improvement in total suspended particulate air quality will occur; most stations experience about a 28 to 30 percent reduction in TSP by 1980. However, none of the eight selected sites will attain the national secondary standard target level (65 $\mu g/m^3$ AAM), and only two sites, (Anaheim and Long Beach), will attain the national primary standard target level, (80 $\mu g/m^3$ AAM). Chino experiences the greatest improvement (40 percent by 1980), but since it starts at an extremely high level, Chino remains above 130 $\mu g/m^3$ even in 1980. The other five sites all remain above the primary standard target level in 1980, ranging from 86 $\mu g/m^3$ at Ontario to 111 $\mu g/m^3$ at Azusa.

As indicated in Table 4-2, the effect of Control Strategy I on emission levels is quite different for each pollutant. In 1980, primary particulate, SO_2, NOx, and RHC emissions are reduced to 66 percent, 21 percent, 82 percent and 37 percent of 1972 levels, respectively. However, in terms of a gross generalization, the overall emission reduction appears to be on the order of 50 percent. As indicated above, this emission reduction results in an air quality improvement on the order of 30 percent. The relative improvement in air quality is significantly less than the relative improvement in emissions. This effect is basically due to high background particulate levels in the Los Angeles Region, (30 to 60 $\mu g/m^3$ at various locations). Emission reductions affect only the non-background portion of particulate matter; thus, total particulate levels generally change less than in proportion to emission level changes.

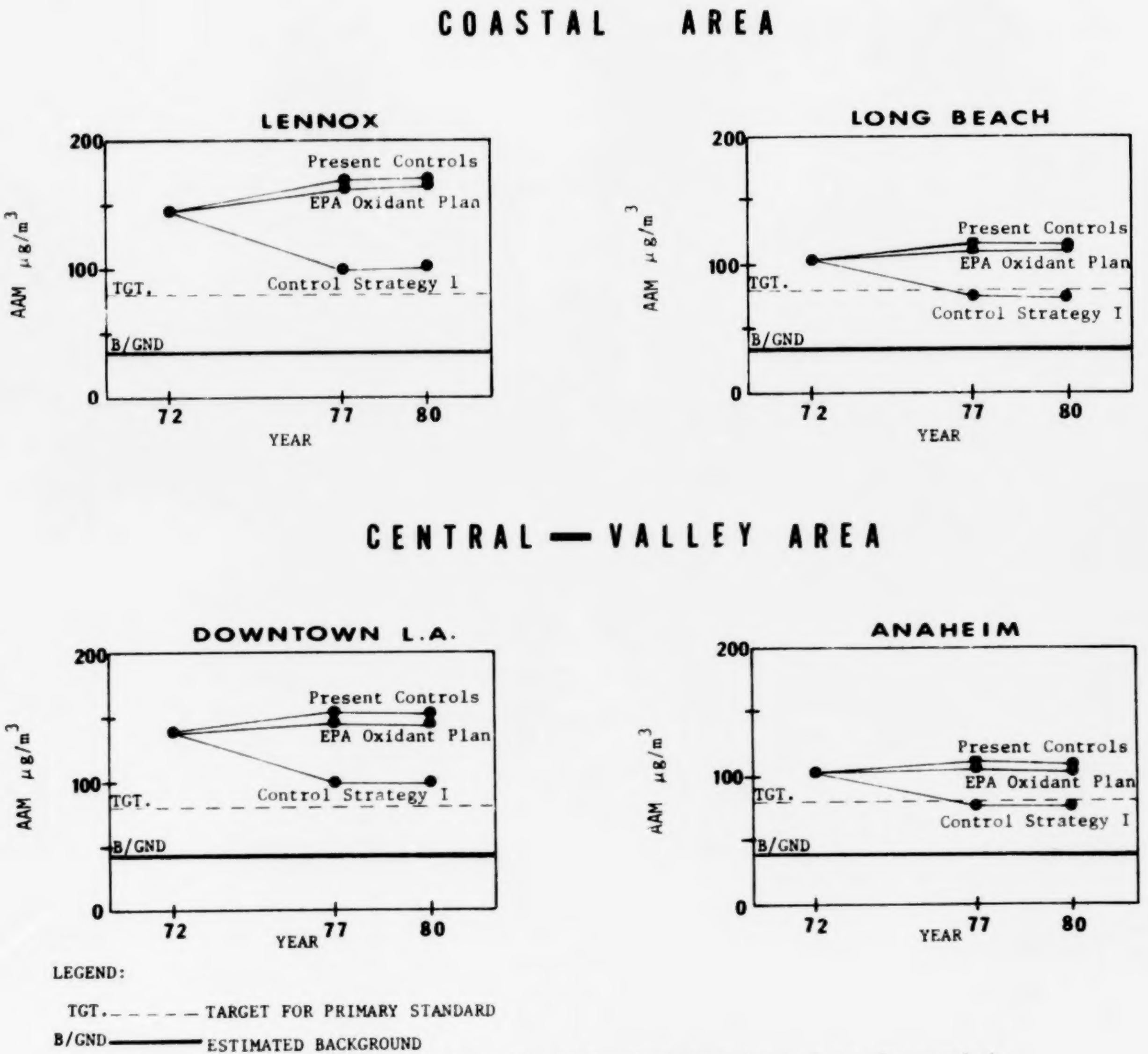

Figure 4-1 Air Quality Impact of Control Strategy I on Suspended Particulate Levels in the Los Angeles Region

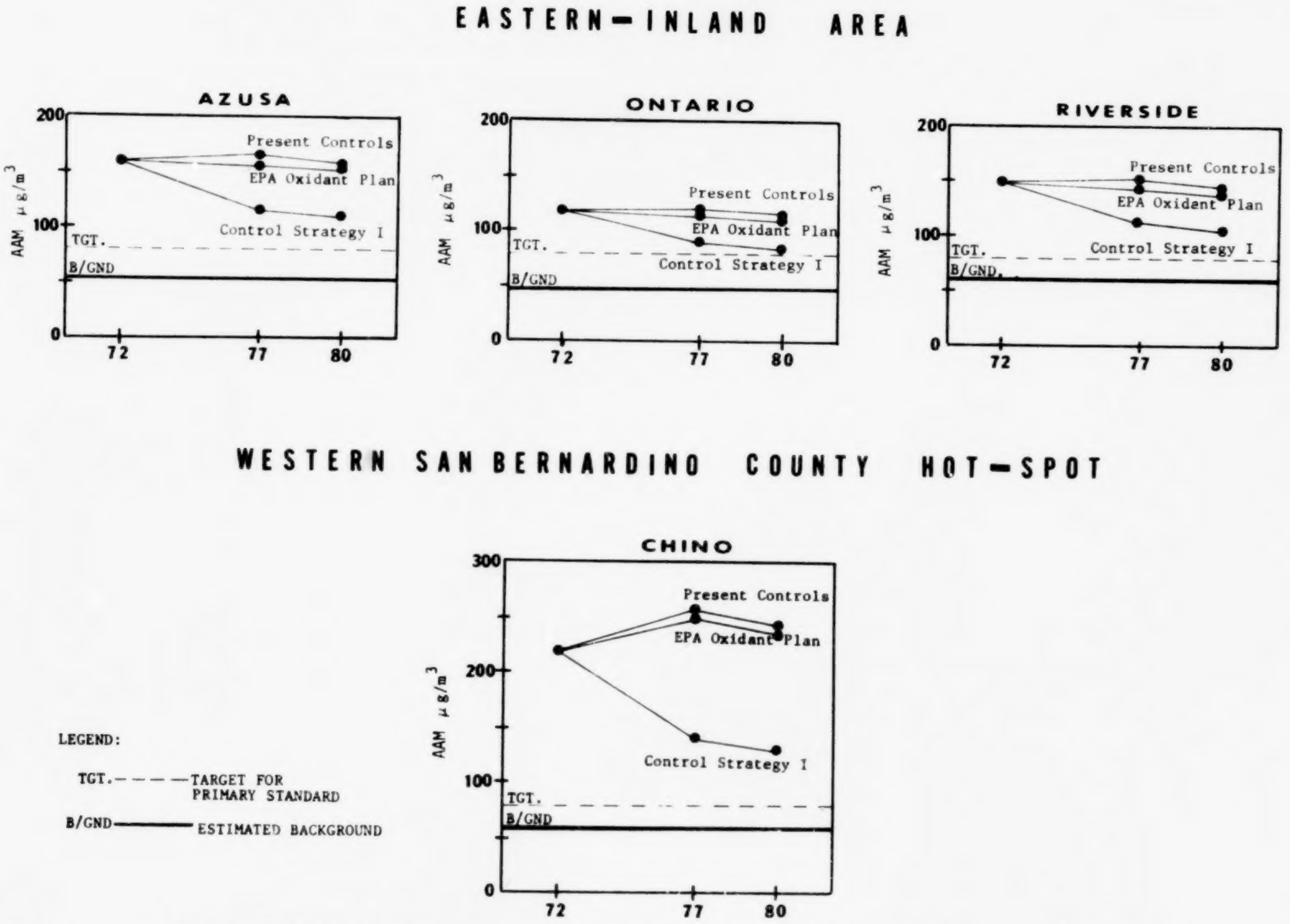

Figure 4-1 Air Quality Impact of Control Strategy I on Suspended Particulate Levels in the Los Angeles Region (Continued)

4.1.3 Control Costs

The cost of implementing the control measures of Control Strategy I is shown in Table 4-4. A scan of the cost effectiveness column shows that the various control measures may be implemented for as low as \$18 per ton of emission controlled to as much as \$3850 per ton of emission controlled. The most costly measures (in terms of cost-effectiveness) are those which are proposed for prevention of particulate and SO_2 emissions from motor vehicles. Collectively measures G.1 and G.2 (desulfurization of motor fuels and retrofitting of particulate traps) will cost \$2260 per ton of total particulate emissions controlled. Reduction of motor vehicle SO_2 emission is obtained by executing control measure G.1 (desulfurization of motor fuel) at a cost of \$1680 per ton. The most cost effective control measure for prevention of particulate emissions is modification of jet aircraft ground operations. Initiation of this control measure at the major airports in the 4 County Area would cost \$300 per ton of particulate emission prevented. SO_2 emissions are most economically controlled by SO_2 removal systems in the metallurgical industry. The cost of SO_2 recovery for these installations is only \$101 per ton of SO_2 removed. NO_x emissions are most economically managed by controls applied to stationary fuel combustion emission sources. Application of water injection or exhaust gas recirculation in stationary internal combustion engines can effect NO_x emission control at a cost of only \$18 per ton.

In general, the overall control of primary particulates constitutes the most costly (on a dollar per ton basis) part of Control Strategy I. The cost summary below shows that both SO_2 and NO_x emissions are controlled at substantially less cost per ton than are particulates. However, because

TABLE 4-4

COST OF CONTROL MEASURES FOR CONTROL STRATEGY I (REASONABLE/IMPLEMENTABLE SCENARIO FOR 1977 & 1980)

SOURCE CATEGORY	CONTROL MEASURE	INITIAL COST	INCREASED ANNUAL OPERATING COST	ANNUALIZED COST	COST EFFECTIVENESS ($/TON)		
		MILLIONS OF DOLLARS			Suspended Particulates	SO_2	NOx
A. Petroleum	A.1 Improve efficiency of regenerator unit dust control system from 95% to 99% by upgrading precipitator.	1.8	.6	.25	$ 512	--	--
	A.2 Desulfurize (to .05% S) all petroleum feed to catalytic cracker	70	12	19	--	$964	--
B. Stationary Fuel Combustion	B.1 High efficiency electrostatic precipitators or baghouses applied to power plant boilers, large non-power plant boilers & refinery heaters	159 80	21.4 26.2	40.0 42.5	$1520 $1540	-- --	-- --
	B.2 Desulfurize fuel oils to .05% S) with new desulfurization technology (applied to power plant boilers & large non-power plant boilers).	480	70	118	--	$1040	--
	B.3 SO_2 removal systems on stacks of refinery heaters	95.1	6.4	15.9	--	$1310	--
	B.4 Low excess air firing & flue gas recirculation for small power plant boilers & large/medium size non-power plant boilers	28.5	.7	5.2	--	--	$580
	B.5 Low excess air firing for refinery heaters	11.0	- .7	1.1	--	--	$111
	B.6 Water injection or exhaust gas recirculation for stationary internal combustion engines	1.3	.02	.44	--	--	$ 18
C. Organic Solvent Operations	C.1 Water wash equipment for all paint spray booths	12.6	.1	1.3	$ 724	--	--
D. Metallurgical Processes	D.1 Baghouses for furnaces with uncontrolled particulate emissions	18.6	1.5	3.4	$1242	--	--
	D.2 SO_2 removal systems for all furnace effluent stacks.	4.0	.1	.5	--	$ 101	--
E. Chemical Industry	--------------------	----	----	----	--	--	--
F. Minerals Industry	--------------------	----	----	----	--	--	--
G. Motor Vehicles	G.1 Desulfurization of motor fuels to 100 ppm sulfur content	80	13.8	21.8	$3850	$1680	--
	G.2 Particulate traps for motor vehicle without catalytic converters. (These devices will replace standard mufflers)	28.5	0	11.5	$1500	--	--
H. Aircraft Operations	H.1 Combination of: a) modification of ground operations, towing of jet aircraft to avoid taxi-idle emissions (only after landing - and	1.2	.5	.6 (ground operation)	$ 300[a]	$740[a]	--
	b) water injection for jet engines	13.6	1.9	4.1			
	Total cost for above combination measures	14.8	2.4	4.8	--	--	$89
All Source Categories	All of controls listed above	896	119	226			

NOTES:

1. The cost totals do not include costs for control measure A.2. This is because control measures B.2 and G.1 require the same equipment which control A.2 would use. Also, the operating costs of equipment under B.2 and G.1 would include the operating costs required by A.2.

2. Costs for each control measure are based on emission control attained in 1977, with the exception of control measure B.2, for which costs are based on emission control by 1980.

a. The cost effectiveness of particulate and SO_2 control from this combination measure was calculated based on H.1.a only because H.1.b has no substantial effect on particulate or SO_2 emissions.

OVERALL COSTS OF CONTROL OF SPECIFIC EMISSION TYPES

	Particulate	SO_2	NO_x
Annualized cost (millions)	$ 70	$ 145	$ 11
Cost Effectiveness ($ per ton removed)	1640	890	860

Note: Costs of those measures which effect control of more than one pollutant type were proportioned equally among the pollutant categories for the purposes of the above comparison.

of the different degrees of emission control obtained by the strategy for the pollutant categories, and because of the appreciable differences in the inventories of the pollutants, the greatest cost of the overall strategy is consumed by control measures affecting removal of SO_2 emissions.

The cost effectiveness of a given type of control will vary according to the degree of pollution which is available for cleanup. For example, SO_2 removal systems are shown to cost $101 per ton of SO_2 removed when installed to manage emissions of metallurgical furnaces, but cost $1310 per ton of SO_2 removed when treating effluent gases from refinery heaters. The difference in cost effectiveness is due in large part to the more concentrated emissions of SO_2 which were available for control from lead melting furnace effluents.

Although it would be absurd to term Control Strategy I economical, its relative low cost and superior cost-effectiveness in relation to the other control scenarios is a major reason for its designation as "Reasonable/Implementable." Table 4-4 shows that the total annualized cost of Control Strategy I is $226 million. If this amount was to be assessed as a tax on automobile gas in the 4 County Area, it would amount to a

4.5 cents per gallon price increase. Expressed in cost per capita, the figure is $24 per person each year. The initial capital required for the overall control plan is $896 million, and annual operating costs are $119 million.

The most significant control measures in the plan, both in terms of emission control quantities and overall cost, are those which would provide for desulfurization facilities and production of low sulfur petroleum products. If desulfurization were adopted as a universal emission control method for the petroleum, fuel combustion, and motor vehicle emission source categories, the effect of the desulfurization control measures (A.2, B.2, G.1) of Control Strategy I would overlap. The operation of the desulfurization facilities required to produce low sulfur motor fuels (control B.1) and low sulfur fuel oils (control B.2) would insure the delivery of low sulfur petroleum feed stocks to the catalytic cracker (control A.2). The overall cost of the desulfurization strategy of the control plan would therefore, be $140 million per year, and the initial capital required would amount to $560 million. The combined cost effectiveness of the desulfurization measures to reduce SO_2 emissions would be $1570 per ton of SO_2 (with attainment of control implementation by 1980).

It should be recognized that there are many uncertainties associated with the assessment of the cost of the control strategy. The technology for many of the proposed emission control systems is currently in its infancy, and the economics of the newly developed equipment are not well defined. In addition, most of the control measures involve systems which must be custom engineered to the specific application. Hence the cost of a given type of control method may vary substantially depending on the circumstances of the installation and the operating conditions.

Cost figures were based on simplified estimative data presented in the literature and on documented costs of existing installations assumed to be similar to those proposed in this study. The resulting cost evaluation provides the overall magnitude of the economic problems confronting the implementation of the control strategy and a broad comparative view between the costs of the various proposed control measures.

4.1.4 Implementation Problems

Control Strategy I is relatively the most implementable of the four proposed control scenarios. Yet a simple inspection of the main elements of the plan indicates there will be serious technological, socio-economic, and administrative problems associated with its implementation. Numerous public and private groups will sustain major adverse impacts. These groups include refineries, industrial process corporations, the utility companies, governmental enforcement agencies, and the public at large.

One of the most obvious implementation problems involves the status of the control equipment technology. Some of the proposed control measures would require the use of equipment which currently is in the infant stages of refinement. The limited production and operating history of desulfurization complexes, stack SO_2 removal systems, and motor vehicle particulate traps raise important questions as to the suitability of widespread legislation of these controls in the very near future.

Another obvious implementation problem concerns the high cost of the proposed control measures. Because most of the controls are targeted for private industry, the most substantial costs of Control Strategy I are expected to be sustained by industrial firms. These firms include the petroleum industry, the electric power utilities, the metallurgical industry, the air travel companies, the automobile industry, and process industries in general. Under Control Strategy I, the petroleum industry would bear approximately 62 percent of the total implementation cost, amounting to an initial capital of $560 million and an annualized cost of $140 million. While these costs would ultimately be borne by the consumer, the petroleum industry would likely be quite reluctant to finance the initial investments. In official testimony before the Committee on Public Works in 1973, Shell Oil Company expressed concern about the availability of capital needed for desulfurization of automobile fuels and the physical capability of the industry to construct the needed facilities according to the specified time tables. In addition, Shell cautioned that desulfurization facilities would require additional energy expenditures, which in the light of current national energy shortages, would impose severe hardships on society. The position taken by Shell Oil is representative of that of other oil companies. Hence, collectively the petroleum industry can be expected to offer powerful resistance against the implementation of Control Stragegy I.

Equipment lead time is another very real problem associated with successful implementation. Because many of the proposed control measures involve newly developed control technology which has been used only sparingly to date, the manufacturers of the associated control equipment are not yet geared to large supply volumes such as would be needed under the proposed implementation schedule. Hence, the ability of the equipment manufacturers to supply some of the control systems within the allowable lead time is very uncertain. In the case of control measures requiring large electrical precipitators, baghouses, and desulfurization facilities, it is not even clear that equipment manufacturers could obtain the needed raw materials prior to the actual operating emission compliance schedules. Some control measures, such as the motor vehicle particulate traps, may require additional development effort before they can be placed into production status.

A fair portion of the impact of the control strategy is dependent on its acceptance by the public. The accepatance level depends to a great extent on an awareness of the air pollution problem and a recognition of the limited means of providing immediate relief to this problem. Traditionally, conservationist groups have been relatively ineffective in the widespread conveyance of this awareness. Instead, the more influential private interests have often effectively controlled opinion. However, there is recent evidence which indicates a waivering balance in the struggle of opinion control relating to conservationist issues. This is true in California where public acceptance of a shoreline conservation measure was voted into law amidst substantial opposition posed by the traditional private interest elements. While such indicators of a changing public awareness are encouraging it is unclear how widespread public acceptanct of Strategy I would be.

Additional obstacles to implementation of the proposed control strategy will very likely be generated by governmental institutions now having jurisdication over emission source control in the 4 County Area. Promulgation of a particulate control program by the Environmental Protection Agency would mandate action by other appropriate governmental agencies which might possibly be in conflict with their present official position. For example, the implementation of controls generally requires action by 1) the state legislature, 2) California Air Resources Board, and/or 3) the affected air pollution control districts. Execution of the control measure requiring particulate trap retrofits to motor vehicles could conceivably meet resistance from any of the above agencies, manifesting delays in the implementation schedule, or possibly, legal suits in the courts. While stationary source measures require no authorizing legislation or action by the Air Resources Board, local APCD's could conceivably offer resistance to enforcement of the EPA promulgated controls if they are sufficiently committed to conflicting emission source policies.

4.2 CONTROL STRATEGY II: MAXIMAL TECHNOLOGICAL CONTROL FOR 1977

The objective of Control Strategy II is the attainment of "maximal technological control by 1977." Here, maximal technological control for 1977 means that the most efficient (for 1977) emission reduction measures of Chapter 3 are selected. These measures lead to higher costs and greater implementation problems than those associated with Control Strategy I.

The left hand side of Table 4-5 lists the control measures contained in Control Strategy II. The reader is referred to Chapter 3 or to Support Document #4 for comprehensive descriptions of these measures. As seen by comparing Table 4-5 to Table 4-1, Control Strategy II differs from Control Strategy I in four basic respects:

(1) In Strategy II, SO_2 stack gas removal devices are used for catalytic crackers instead of desulfurization of the cracker feed. Since a general policy of desulfurization is not followed in Strategy II, the less expensive but equally efficient stack gas removal devices are chosen for catalytic crackers.

(2) In order to attain maximal SO_2 control from stationary fuel combustion sources by 1977, SO_2 stack gas removal systems are used in Strategy II. This avoids the delay in Strategy I associated with fuel oil desulfurization which can be only partially implemented by 1977.

(3) In Control Strategy II, SO_2 scrubber/particulate trap systems are used on all vehicles. Strategy I calls only for particulate traps on vehicles without catalytic mufflers. Both strategies include desulfurization of all motor fuels.

(4) Modification of aircraft ground operations is done only after landing in Strategy I; Strategy II also calls for modifications before take-off. The latter may be much harder to implement because of safety considerations. Strategy II also adds modification of compressor airbleed for RHC control, another measure of uncertain implementability.

It should be noted that the EPA oxidant implementation plan is specified by Control Strategy II, as it is in all strategies considered here.

TABLE 4-5 CONTROL STRATEGY II - MAXIMAL TECHNOLOGICAL CONTROL FOR 1977

Note: The EPA Oxidant Implementation Plan is Assumed as Part of this Strategy

		Emission Reductions (tons/day)							
		1977				1980			
Source Category	Proposed Control Measures for Strategy II	Susp. Part.	SO_2	NO_x	RHC	Susp. Part.	SO_2	NO_x	RHC
A. Petroleum Industry	A.1 Improve efficiency of regenerator unit dust control systems from 95% to 99% (by upgrading precipitators)	2	---	---	---	2	---	---	---
	A.2 SO_2 stack gas removal devices for catalytic crackers	---	51	---	---	---	51	---	---
B. Stationary Fuel Combustion	B.1 High efficiency baghouses applied to power plant boilers, large non-power plant boilers, and refinery heaters	64	---	---	---	64	---	---	---
	B.2 SO_2 removal systems for all refinery heaters and all oil-fired boilers	---	336	---	---	---	342	---	---
	B.3 Low excess air firing and flue gas recirculation for small power plant boilers and on large/medium size non-power plant boilers	---	---	242	---	---	---	227	---
	B.4 Low excess air firing for refinery heaters	---	---	26	---	---	---	24	---
	B.5 Water injection or exhaust gas recirculation for stationary internal combustion engines	---	---	66	---	---	---	62	---
C. Organic Solvent Use	C.1 Water wash equipment for all paint spray booths	6	---	---	---	6	---	---	---
D. Metallurgical Processes	D.1 Baghouses for furnaces with uncontrolled particulate emissions	8	---	---	---	8	---	---	---
	D.2 SO_2 removal systems for all furnace effluent stacks	---	14	---	---	---	14	---	---
E. Chemical Industry		---	---	---	---	---	---	---	---
F. Minerals Industry		---	---	---	---	---	---	---	---
G. Motor Vehicles	G.1 Desulfurization of motor fuels to 100 PPM sulfur content and addition of SO_2 scrubber/particulate trap systems to all vehicles	44	44	---	---	43	44	---	---
H. Aircraft Operations	H.1 Modification of ground operations: towing aircraft to avoid taxi-idle emissions (before take-off and after landing). Also, water injection and modified compressor air bleed rate for jet engines	5	1	15	15	7	2	23	22
Total Emission Reductions for Control Strategy II		132	446	349	15	130	453	336	22

4.2.1 Impact on Emission Levels

The right hand side of Table 4-5 presents the emission reductions resulting from Control Strategy II in 1977 and 1980. These reductions are to be subtracted from the emission projections for the EPA oxidant plan which is included as part of the strategy. The resulting projected emissions from Control Strategy II in the 4 County Sub-Area are presented in Table 4-6. A comparison with Strategy I reveals that Strategy II attains slightly higher primary particulate and RHC control. The most significant improvement over Strategy I is a greater reduction in SO_2 emissions by 1977.

TABLE 4-6

EMISSION PROJECTIONS FROM CONTROL STRATEGY II
FOR THE 4 COUNTY SUB-AREA

		PRIMARY SUSPENDED PARTICULATES			NITROGEN OXIDES		
		1972	1977	1980	1972	1977	1980
EMISSION PROJECTIONS UNDER EPA OXIDANT PLAN	(tons/day)	178	223	233	1345	1614	1434
EMISSION RESULTING FROM CONTROL STRATEGY II	(tons/day)		91	103		1265	1098
	(% of 1972)		51%	58%		94%	82%

		SULFUR DIOXIDE			REACTIVE HYDROCARBONS		
		1972	1977	1980	1972	1977	1980
EMISSION PROJECTIONS UNDER EPA OXIDANT PLAN	(tons/day)	444	524	535	1095	547	410
EMISSONS RESULTING FROM CONTROL STRATEGY II	(tons/day)		78	82		532	388
	(% of 1972)		17%	18%		49%	35%

In order to apply the air quality/emission level model to Chino, estimates are required of particulate and SO_2 emission reductions from the Kaiser/Edison complex. Table 4-7 presents the expected emission projections for the Kaiser/Edison complex under Control Strategy II. Here, the only difference from Strategy I is a higher degree of SO_2 control in 1977, (see Table 4-3 for a comparison)

TABLE 4-7

PRIMARY PARTICULATE AND SO_2 EMISSION ESTIMATES FOR THE KAISER/EDISON COMPLEX IN THE WESTERN SAN BERNARDINO COUNTY HOT-SPOT UNDER CONTROL STRATEGY II

	EMISSIONS (% of 1972 LEVEL)	
	1977	1980
PRIMARY PARTICULATES	32%	34%
SO_2	15%	16%

4.2.2 Air Quality Impact

The air quality impact of Control Strategy II is presented in Figure 4-2. Results have been obtained using the particulate air quality model of Section 2.3 for eight monitoring sites in the 4 County Sub-Area. Under Control Strategy II, most sites experience a 31 to 33 percent improvement in suspended particulate air quality. However, as with Strategy I, none of the eight selected locations attains the national secondary standard target level, (65 $\mu g/m^3$ AAM). Two sites, Anaheim and Long Beach, attain the national primary standard target level, (80 $\mu g/m^3$ AAM). Again, Chino experiences the greatest relative improvement (42 percent by 1980), but is still at a level (127 $\mu g/m^3$ in 1980) well in excess of the federal standard. The other five sites remain above the primary target level, ranging from 83 $\mu g/m^3$ to 107 $\mu g/m^3$ in 1980.

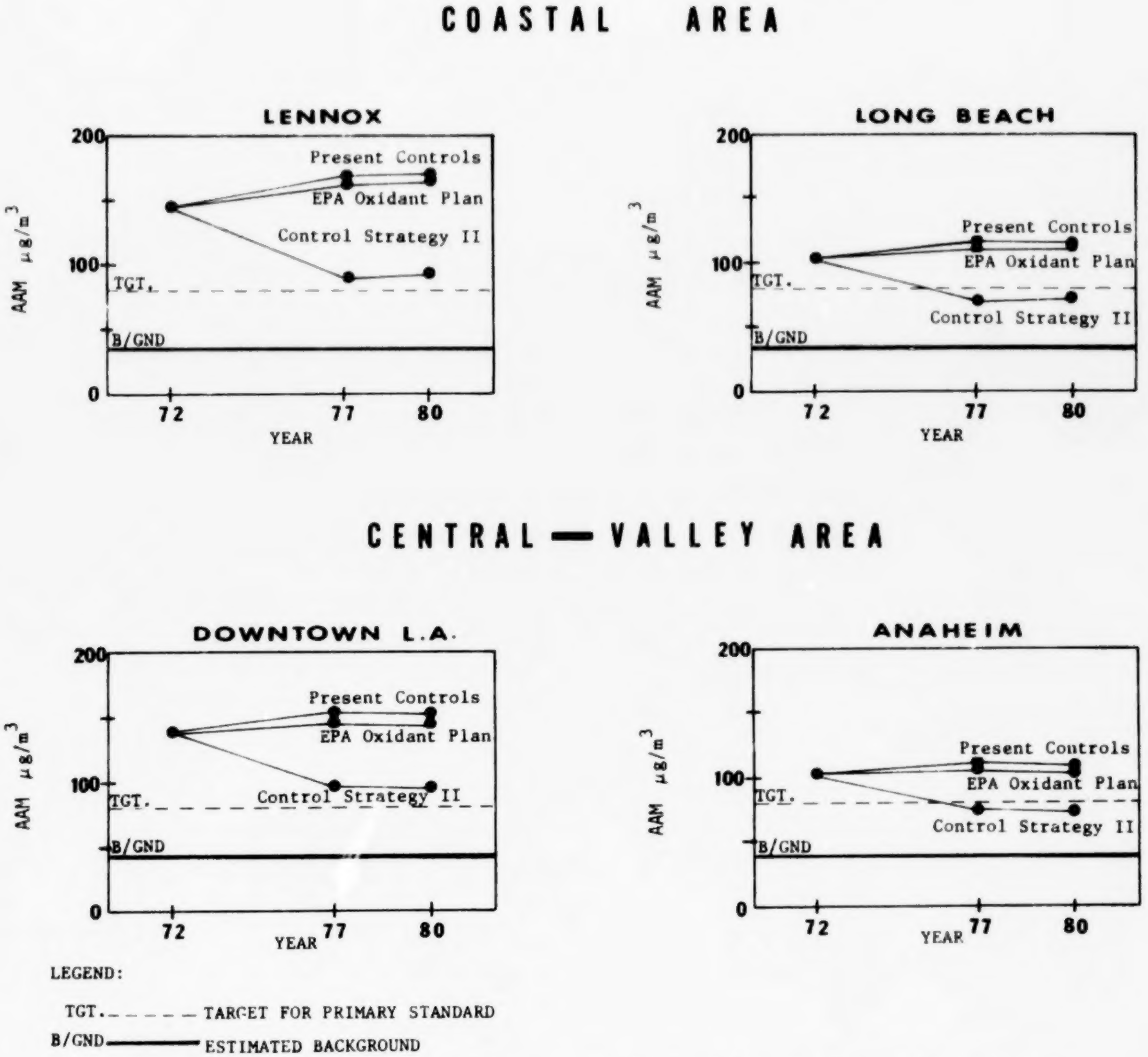

Figure 4-2 Air Quality Impact of Control Strategy II on Suspended Particulate Levels in the Los Angeles Region

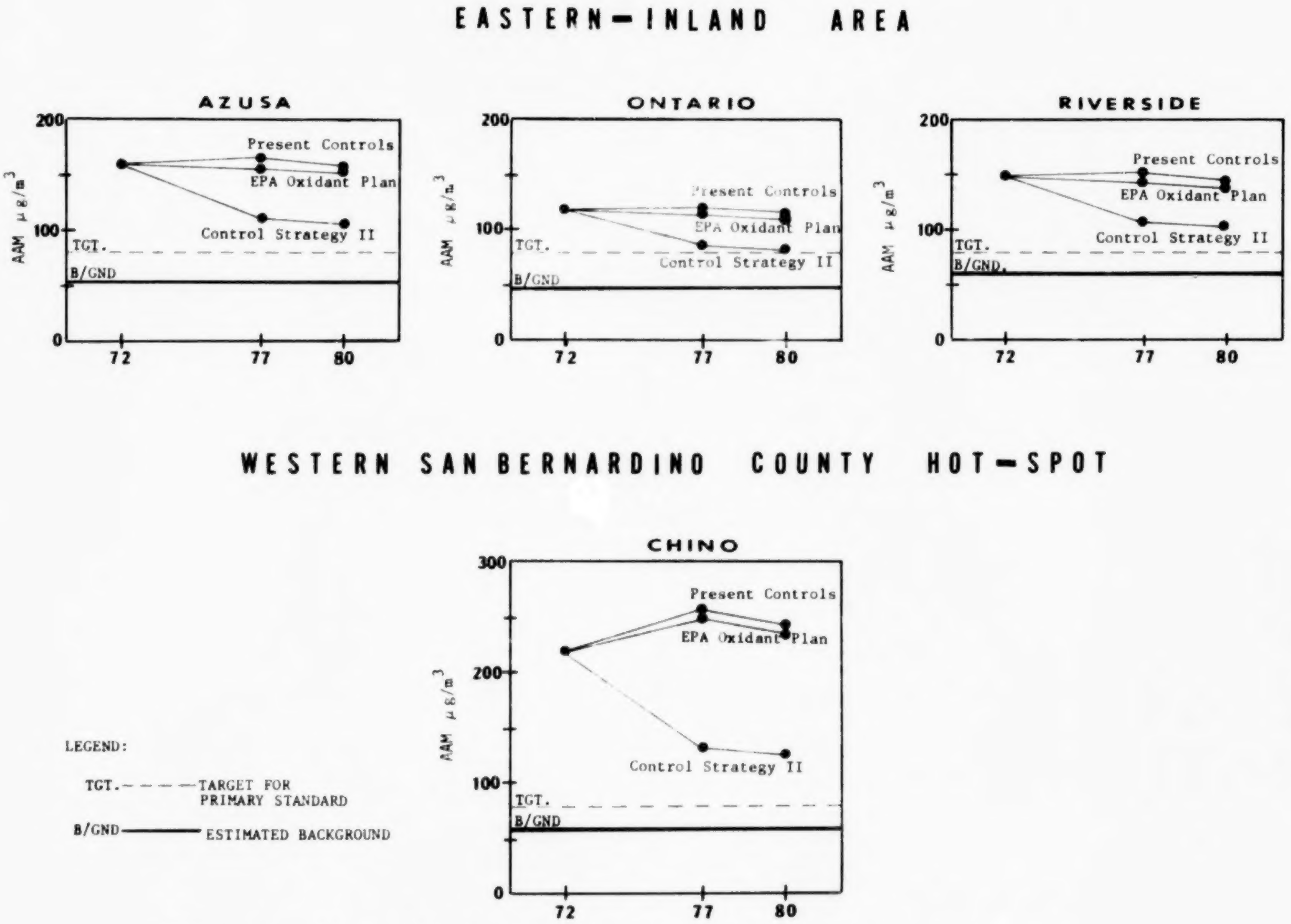

Figure 4-2 Air Quality Impact of Control Strategy II on Suspended Particulate Levels in the Los Angeles Region (Continued)

Strategy II demonstrates some slight air quality advantages over Strategy I. The overall 1980 reductions are 31 - 40 percent for Strategy II and 28 - 40 percent for Strategy I at the various locations. Strategy II compares even more favorably in 1977. However, even in 1977 the advantages over Strategy I are still somewhat marginal, (3 to 4 percent better reductions in 1977).

As with Strategy I, the air quality improvement associated with Strategy II is smaller (on a relative basis) than the emission level improvement. On an overall basis, emission levels are reduced more than 50 percent by Strategy II. Ambient suspended particulate reductions are around 33 percent. As discussed in Section 4.1.3, the relative insensitivity of air quality to emission reductions is due to high background particulate levels in the Los Angeles Region.

4.2.3 Control Costs

The costs of implementing the control measures of Control Strategy II are shown in Table 4-8. The cost-effectiveness ratios of the measures range from as low as \$18 per ton of emissions controlled to as much as \$6300 per ton of emissions controlled. As in Control Strategy I, the least cost-effective measures are those which are proposed for prevention of particulate and SO_2 emissions form motor vehicles. Control measures G.1 and G.2 (desulfurization of motor fuels and retrofitting of SO_2 scrubber/particulate trap mufflers) will cost \$6300 per ton of particulates controlled, and \$6070 per ton of SO_2 emission prevented. The least cost effective control of NO_x is the combination of aircraft measures H.1.a, H.1.b, and H.1.c, at \$1430 per ton of NO_x emissions controlled. The most cost-effective measures included in Control Strategy I are also the most cost-effective under Control Strategy II.

TABLE 4-8

COST OF CONTROL MEASURES FOR CONTROL STRATEGY II (MAXIMAL TECHNOLOGICAL SCENARIO FOR 1977)

SOURCE CATEGORY	CONTROL MEASURE	INITIAL COST	INCREASED ANNUAL OPERATING COST	ANNUAL-IZED COST	COST-EFFECTIVENESS ($/TON)		
		MILLIONS OF DOLLARS			SUSPENDED PARTICULATES	SO_2	NO_x
A. Petroleum Industry	A.1 Improve efficiency of regenerate unit dust control system from 85% to 99% by upgrading precipitator	1.8	.6	.25	$ 512	--	--
	A.2 SO_2 removal system on catalytic regenerator stacks	28	.7	3.8	--	$ 193	--
B. Stationary Fuel Combustion	B.1 High efficiency baghouses applied to power plant boilers, large non-power plant boilers, & refinery heaters	80	26.2	42.5	$1540	-	--
	B.2 SO_2 removal systems for all refinery heaters and all oil fired boilers	773	114	192	--	$1540	--
	B.3 Low excess air firing & flue gas recirculation for small power plant boilers & large/medium size non-power plant boilers	28.5	.7	5.2	--	--	$ 588
	B.4 Low excess air firing for refinery heaters	11.0	-.7	1.1	--	--	$ 111
	B.5 Water injection or exhaust gas recirculation for stationary internal combustion engines	1.3	.2	.44	--	--	$ 18
C. Organic Solvent Operations	C.1 Water wash equipment for all paint spray booths	12.6	.1	1.3	$ 724	--	--
D. Metallurgical process	D.1 Baghouses for furnaces with uncontrolled particulate emissions	18.6	1.5	3.4	$1242	--	--
	D.2 SO_2 removal systems for all furnace effluent stacks	4.0	.1	.5	--	$ 101	--
E. Chemical Industry	----------	----	----	----	----	--	--
F. Minerals Industry	----------	----	----	----	----	--	--
G. Motor Vehicles	G.1 Desulfurization of motor fuels to 100 ppm sulfur content	80.0	13.8	21.8	----	--	--
	and installation of SO_2 scrubber/particulate trap mufflers on all vehicles	147	41	79			
	total cost for above combination measure	227	55	101	$6360	$4670	--
H. Aircraft Operations	H.1 Combination of: a) Modification of ground operations: towing of jet air craft to avoid taxi-idle emissions (before takeoff & after landing) and	1.2	.5	.6	150[a]	370[a]	
	b) Water injection to jet engines and	13.6	1.9	4.1			
	c) Modification of compressor air bleed rate in jet engines b	10.0	1.4	3.0			
	total cost for above combination measure	24.8	3.8	7.7			$1430
All Source Categories	All control measures listed above	1211	206	367			

a. The cost effectiveness of particulate and SO_2 control from this combination measure was calculated based on H.1.a only because H.1.b has no substantial effect on particulate or SO_2 emissions.

b. This control measure is proposed for control of reactive hydrocarbon emissions (it is proposed as the only addition to the EPA RHC strategy). In combination with aircraft towing (ground operations modification) it will account for a reduction of 15 tons/day of RHC emissions. The overall cost effectiveness for the combination control H.1.) is $1430 per ton on RHC emission prevention.

Implementation of Control Strategy II would require a 62 percent greater cost than Control Strategy I. The cost difference is due primarily to those measures proposed for stationary fuel combusion sources and motor vehicle sources. Strategy II would provide for control of SO_2 emissions from stationary fuel combustion with SO_2 removal systems in boiler stacks, rather than by desulfurization of fuel oils (a slightly less effective control, especially in terms of 1977 attainment). The stack control of SO_2 incurs a cost of $58 million more per year than the desulfurization option. The employment of SO_2 scrubber/particulate-trap mufflers to attain higher efficiency control of motor vehicles would cost $68 million per year more than the use of the simple particulate-trap of Control Strategy I. While the petroleum industry was charged with the responsibility of a $140 million annualized cost in Control Strategy I, its expenditure under Control Strategy II would be only $26 million per year. Hence, it is evident that Strategy II provides for a more even distribution of costs among the various private interest than in the first strategy.

Control of primary particulates is more costly (on a dollar per ton basis) than control of SO_2 or NO_x. The cost summary below outlines the expenditures in terms of the pollutant categories controlled.

OVERALL COSTS FOR CONTROL OF SPECIFIC EMISSION TYPES

	Particulates	SO_2	NO_x
Annualized Cost (millions)	$ 98	$247	$ 11
Cost Effectiveness ($ per ton of prevention)	$2060	$1510	$860

Note: Costs of those measures which effect control of more than one pollutant type were proportioned equally among the pollutant categories for the purposes of the above comparison.

The combination of controls comprising the Maximal Technological Control Strategy for 1977 would be implemented at a cost of $360 million per year. Assessed as a tax on automobile gas in the Four County Area, this cost would translate to a 7.3 cents per gallon price increase. Expressed in cost per capita, the figure would be $38 per person per year. The initial capital required for the overall control plan is $1211 million. Annual operating costs would be $206 million.

Unlike Control Strategy I, there are no substantial overlaping impacts between the control measures of Strategy II. Whereas the main theme of Control Strategy I was desulfurization, the theme of Strategy II could probably be termed "add-on control." Except for the desulfurfurization of motor fuels (which really has a minor effect on motor vehicle emissions after the SO_2 scrubber/particulate trap is incorporated), all of the other major control measures of the plan involve the incorporation of add-on emission control equipment.

It should be remembered once again (see Section 4.1.3) that the cost figures developed in this study are based on simplified estimative data presented in the literature, and on documented costs of existing installations assumed to be similar to those proposed in this study. The resulting cost evaluation is, therefore, only a preliminary indicator of the economic impact associated with the strategy implementation.

4.2.4 Implementation Problems

Because of its high cost, Control Strategy II would present more implementation problems than Control Strategy I. Strategy II imposes a 62 percent greater cost than Strategy I. Most of the increased cost is sustained by the motor vehicle owner, the electric power utilities, and process industries with fuel combustion emission sources. The latter two sectors will absorb 36 percent of the total implementation cost, and the former, 22 percent. On the other hand, the petroleum industry will suffer far less than under Control Strategy I (the "desulfurization strategy") since its expenditures will be reduced from an annualized cost of $140 million to $26 million. While it should be remembered that all control costs are eventually borne by the consumer, it is also evident that each of the private interests having responsibility for initial capital outlay may be expected to lobby extensively against the control strategy.

Most of the problems confronting the administration of Strategy II are similar to those which would be encountered with Control Strategy I (section 4.1.4). The plan involves essentially the same type of control measures, although it is weighted heavily with "add-on" controls in preference to the desulfurization control theme of the first scenario. Because of the increased number of stack SO_2 removal systems required by the plan, it may be very difficult to insure supplier delivery of this required volume by the scheduled compliance dates. The combined number and size of the required SO_2 cleanup systems would surpass that which is already operative as installed units throughout the nation.

Implementation of the control measure which would provide for retrofitting motor vehicles with SO_2 scrubber/particulate trap mufflers could conceivably be delayed by development problems. The device is not yet technologically refined and requires more testing and design effort before it can be placed into production. In addition, enforcement of the retrofit will face legal and institutional obstacles, as it must receive legislative authorization and Air Resources Board testing approval.

As in Control Strategy I implementation will be encumbered by certain technological problems, equipment lead time difficulties, public acceptance problems, and administrative and enforcement complications. While a detailed assessment of the magnitude and extent of these difficulties is beyond the scope of this study, it is clear that the successful execution of Control Strategy II would require an extensive organizational mechanism to deal very rapidly with the elimination of these technical, socio-economic, and administrative obstacles.

4.3 CONTROL STRATEGY III: A DELAYED SCENARIO FOR 1980 BASED ON METHANOL CONVERSION

The third alternative control strategy centers around methanol conversion for stationary combustion sources which presently burn fuel oil or refinery make gas. Strategy III is a delayed scenario since it requires a relatively long implementation time. It is assumed here that methanol conversion can be fully implemented for stationary sources by 1980, but that negligible conversion can be accomplished by 1977, (see Support Document #4 for a discussion of market demand and construction requirements).

Methanol conversion results in a very high degree of control for particulate, SO_2, and NO_x emissions from stationary combustion sources. The efficiency for particulate emissions is about the same as the measures proposed in Strategies I and II, (approximately 99 percent for the sources which are affected). The efficiency for SO_2 and NO_x is substantially higher than attained by the measures in Strategies I and II. Possibly an even greater advantage of the methanol conversion strategy is the impact on projected energy problems. Methanol can be produced from low grade coal or even from certain types of refuse. The methanol conversion scheme can thus help to alleviate the supply problem associated with petroleum based fuels. A detailed description of the methanol control measure and associated impacts, costs, and implementation problems can be found in Support Document #4.

The left hand side of Table 4-9 list the control measures to be included in Strategy III. As noted above, the principal change from Strategies I and II is the substitution of methanol conversion in place of several other controls for stationary combustion sources. The remainder of Strategy III is identical to Strategy I, (the reasonable/implementable strategy), with two exceptions. These exceptions have been made in order to make Strategy III more compatible with a policy of methanol conversion in the long run. In the long term, (post 1980), it might prove best to convert nearly all petroleum fuel users (mobile as well as stationary) to methanol on a nationwide basis. Accordingly, there would be a general phasing out of petroleum fuel production and use. To be compatible with this phasing out, exhaust gas treatment add-on devices are chosen in Strategy III for both catalytic crackers and automobiles rather than the desulfurization options for cracker feed and motor fuel which represent long-term capital commitments in the petroleum industry.

TABLE 4-9 CONTROL STRATEGY III - A DELAYED SCENARIO FOR 1980 BASED ON METHANOL CONVERSION

Note: The EPA Oxidant Implementation Plan is Assumed as Part of This Strategy

SOURCE CATEGORY	PROPOSED CONTROL MEASURES FOR STRATEGY III	EMISSION REDUCTIONS (TONS/DAY)							
		1977				1980			
		SUSP. PART.	SO_2	NO_x	RHC	SUSP. PART.	SO_2	NO_x	RHC
A. Petroleum Industry	A.1. Improve efficiency of regenerator unit dust control systems from 95% to 99% by upgrading precipitators. (Includes reduction in operations from B.1. below.	2	---	---	---	2	---	---	---
	A.2. SO_2 stack gas removal devices for catalytic crackers. (Includes reduction in operations from B.1. below).	---	51	---	---	---	51	---	---
B. Stationary Fuel Combustion	B.1. Conversion of all boilers and heaters using fuel oil or refinery make gas to methanol fuel by 1980.	---	---	---	---	64	379	328	---
	B.2. Water injection or exhaust gas recirculation for stationary internal combustion engines.	---	---	66	---	---	---	62	---
C. Organic Solvent Use	C.1. Water wash equipment for all spray booths.	6	---	---	---	6	---	---	---
D. Metallurgical Processes	D.1. Baghouses for furnaces with uncontrollable particulate emissions.	8	---	---	---	8	---	---	---
	D.2. SO_2 removal systems for all furnace effluent stacks.	---		14	---	---	14	---	---
E. Chemical Industry		---	---	---	---	---	---	---	---
F. Minerals Industry									
G. Motor Vehicles	G.1. SO_2 scrubbers/particulate trap systems for all vehicles.	42	44	---	---	41	45	---	---
H. Aircraft Operations	H.1. Modification of ground operations: towing of aircraft to avoid taxi-idle emissions, (only after landing). Also, water injection for jet engines.	2	1	15	6	3	1	22	8
		1977				1980			
		SUSP. PART.	SO_2	NO_x	RHC	SUSP. PART.	SO_2	NO_x	RHC
TOTAL EMISSION REDUCTIONS FROM CONTROL STRATEGY III (TONS/DAY)		60	110	81	6	124	490	412	8

4.3.1 Impact on Emissions Levels

The right hand side of Table 4-9 presents the emission reductions to be expected from Control Strategy III in 1977 and 1980. As evidenced by the table, methanol conversion of boilers and heaters is the dominant control measure. Since methanol conversion is not attained until 1980, the 1980 emission reductions are much larger than the 1977 reductions.

The emission reductions of Table 4-9 are to be subtracted from the baseline emission projections for the EPA oxidant plan which is included as part of the proposed control strategy. Table 4-10 presents the resulting emission projections for the 4 County Sub-Area under Control Strategy III. A comparison with Strategies I and II, (Tables 4-2 and 4-6), reveals that Strategy III leaves greater particulate, SO_2, and NO_x emissions in 1977 but attains considerably lower SO_2 and NO_x levels by 1980.

TABLE 4-10

EMISSION PROJECTIONS FROM CONTROL STRATEGY III
FOR THE 4 COUNTY SUB-AREA

		PRIMARY SUSPENDED PARTICULATES			NITROGEN OXIDES		
		1972	1977	1980	1972	1977	1980
EMISSION PROJECTIONS UNDER EPA OXIDANT PLAN	(tons/day	178	223	233	1345	1614	1434
EMISSIONS RESULTING FROM CONTROL STRATEGY III	(tons/day		163	109		1533	1022
	(% of 1972)		92%	61%		114%	76%

		SULFUR DIOXIDE			REACTIVE HYDROCARBONS		
		1972	1977	1980	1972	1977	1980
EMISSION PROJECTIONS UNDER EPA OXIDANT PLAN	(tons/day)	444	524	535	1095	547	410
EMISSIONS RESULTING FROM CONTROL STRAGEGY III	(tons/day)		414	45		541	402
	(% of 1972)		93%	10%		49%	37%

In order to apply the air quality/emission level model to the Chino monitoring site, estimates are required for the effect of each strategy on particulate and SO_2 emissions at the Kaiser/Edison Complex. Table 4-11 presents the expected particulate and SO_2 emissions for Kaiser/Edison under Control Strategy III. The difference in Strategy III from the first two strategies is demonstrated even more dramatically here. The delayed scenario initially yields an increase in particulate and SO_2 emissions from Kaiser/Edison, followed by a drastic decrease as methanol conversion is implemented between 1977 and 1980.

TABLE 4-11

PRIMARY PARTICULATE AND SO_2 EMISSION ESTIMATES FOR THE KAISER/EDISON COMPLEX IN THE WESTERN SAN BERNARDINO COUNTY HOT-SPOT UNDER CONTROL STRATEGY III

	EMISSIONS (% of 1972 LEVEL)	
	1977	1980
PRIMARY PARTICULATES	108%	34%
SO_2	115%	5%

4.3.2 Air Quality Impact

Figure 4-3 presents the air quality impact of Control Strategy III at the eight monitoring sites in the 4 County Sub-Area. The delayed nature of the methanol control strategy is evident in Figure 4-3. In 1977, only marginal improvements in air quality are attained, (about 10 percent better than 1972 levels at most stations). Between 1977 and 1980, significant reductions in particulate levels are achieved at each station.

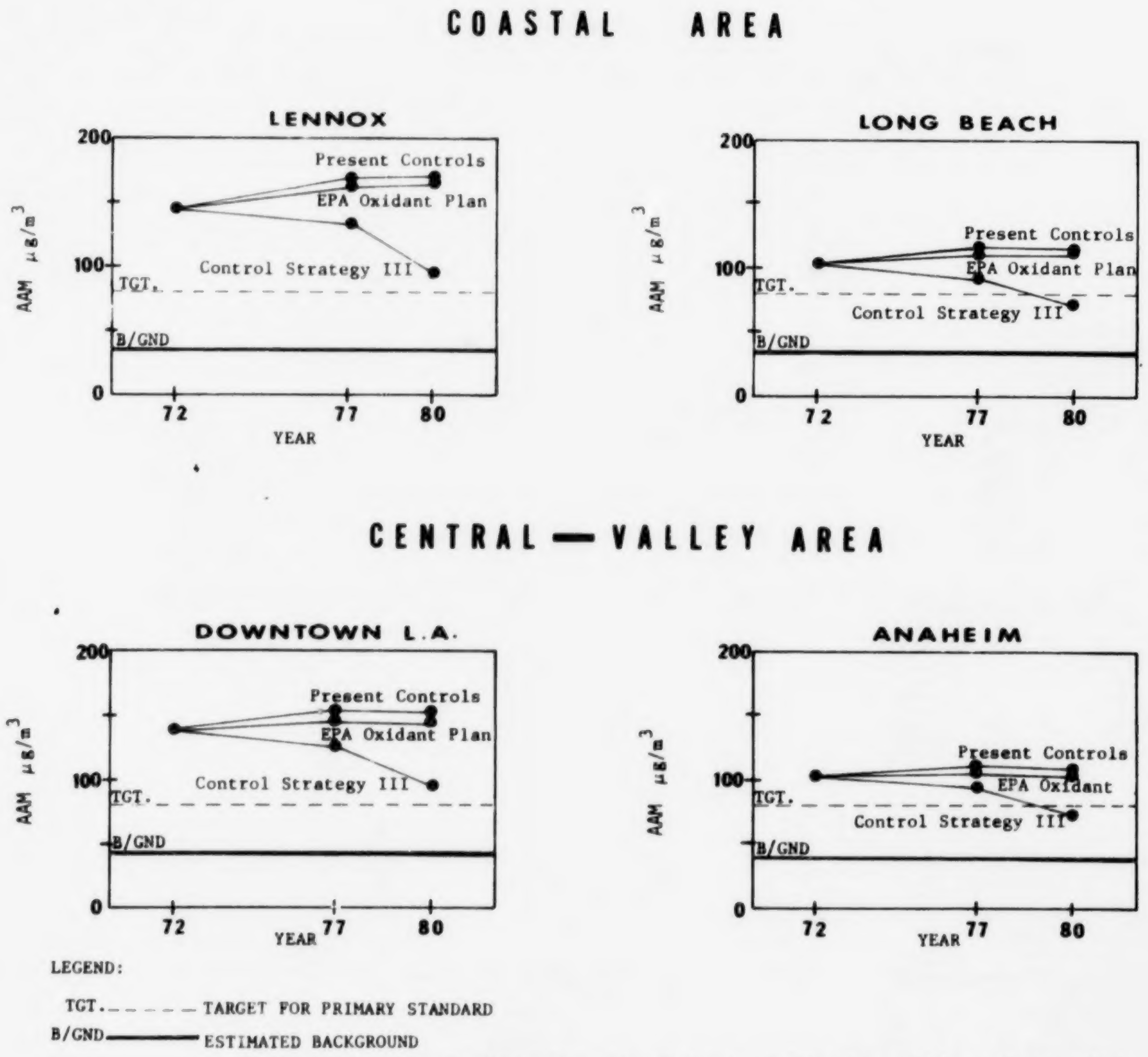

Figure 4-3 Air Quality Impact of Control Strategy III on Suspended Particulate Levels in the Los Angeles Region

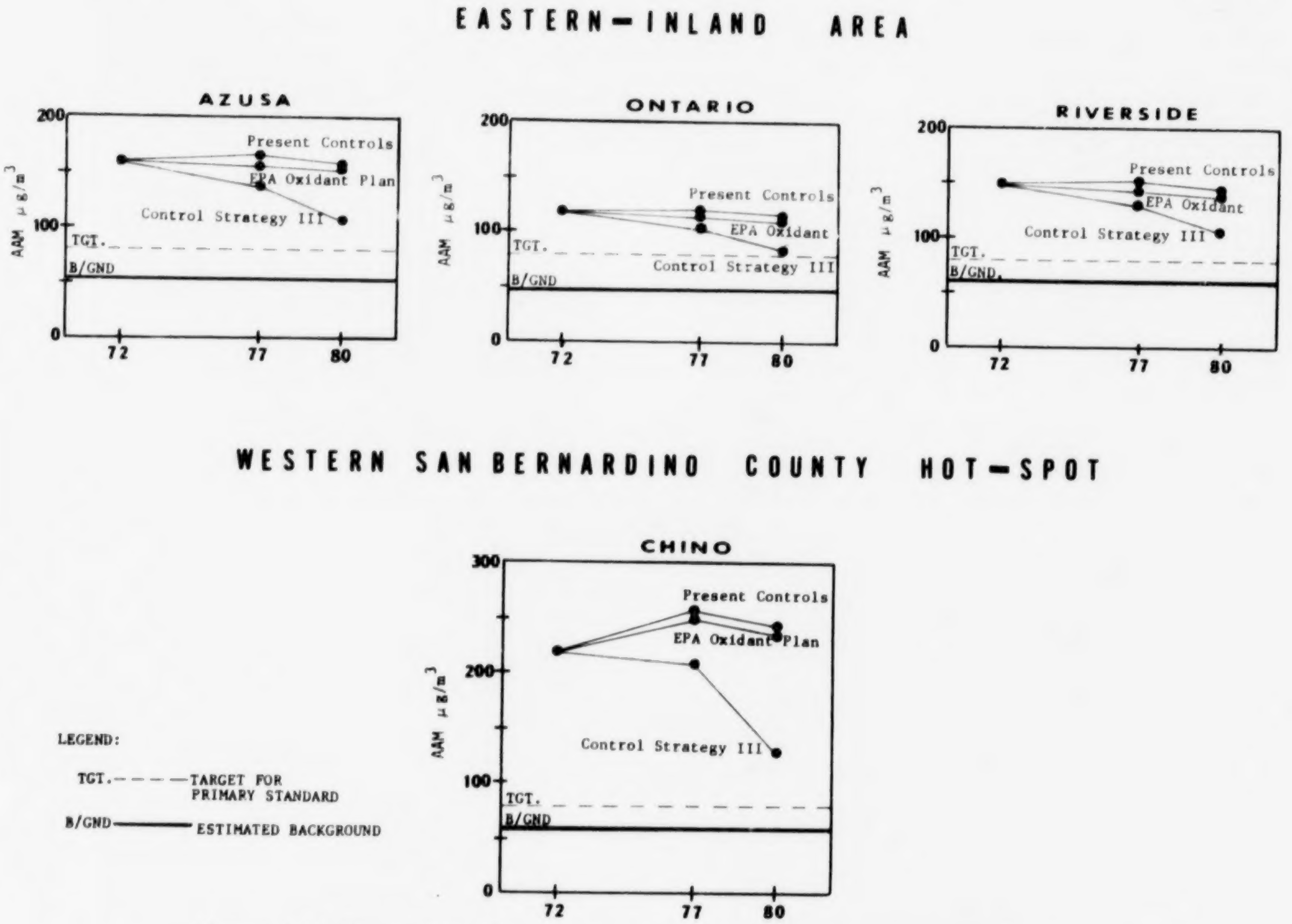

Figure 4-3 Air Quality Impact of Control Strategy III on Suspended Particulate Levels in the Los Angeles Region (Continued)

In 1980, the air quality levels under Strategy III are very similar to those under Strategy II, (the maximal technological scenario). Most sites experience a 30 to 34 percent improvement in suspended particulate air quality by 1980. No stations reach the target level for the secondary national particulate standard, (65 $\mu g/m^3$). Anaheim and Long Beach attain the national primary standard target level, (80 $\mu g/m^3$). Chino experiences the greatest improvement (42 percent by 1980), but still remains at the highest level of all the sites, (127 $\mu g/m^3$ in 1980). These are almost exactly the same results as Strategy II for 1980. The main difference between the air quality impacts of Strategies II and III is that the latter achieves only about a third of the improvement associated with the former in 1977.

4.3.3 Control Costs

The implementation costs of the delayed scenario for 1980 based on methanol conversion are shown in Table 4-12. The strategy is essentially the same as Control Strategy I (Reasonable/Implementable Plan) with the main exceptions that control of fuel combustion equipment is accomplished by conversion to the cleaner burning methanol fuel, and the desulfurization measures of Strategy I have been omitted (in anticipation of the eventual universal conversion of all petroleum fuel use to methanol). These significant distinctions produce a total cost for the Methanol Strategy of $235 million per year, which is nearly the same as the implementation cost of Control Strategy I (Reasonable/Implementable). However the initial capital required for execution of the plan is $1650 million, substantially more than each of the first two control strategies. These high capital costs are offset by the fact that there are no increases in operating costs for the methanol production facilities over the previous

TABLE 4-12

COST OF CONTROL MEASURES FOR CONTROL STRATEGY III (DELAYED METHANOL CONVERSION SCENARIO FOR 1980)

SOURCE CATEGORY	CONTROL MEASURE	INITIAL COST	INCREASED ANNUAL OPERATING COST	ANNUALIZED COST	COST EFFECTIVENESS ($/TON)		
		MILLIONS OF DOLLARS			Suspended Particulates	SO_2	NO_x
A. Petroleum Industry	A.1 Improve efficiency of regenerator unit dust control system from 95% to 99% by upgrading precipitator	1.8	.6	.25	$ 512	----	----
	A.2 SO_2 removal system on catalytic regenerator stacks	28	.7	3.8	----	$ 193	----
B. Stationary Fuel Combustion	B.1 Conversion of all boilers and heaters using fuel oil or refinery make gas to methanol fuel by 1980.	1422	0	142	$6000[a]	$1030[a]	$1190[a]
	B.2 Water injection or exhaust gas recirculation for stationary internal combustion engines	1.3	.2	.44	----	----	$ 18
C. Organic Solvent Operations	C.1 Water wash equipment for all Paint spray booths	12.6	.1	1.3	$ 724	----	----
D. Metallurgical process	D.1 Baghouses for furnaces with uncontrolled particulate emissions	18.6	1.5	3.4	$1242	----	----
	D.2 SO_2 removal systems for all furnace efficient stacks	4.0	.1	.5	----	$ 101	----
E. Chemical Industry	-------------------	----	----	----	----	----	----
F. Minerals Industry	-------------------	----	----	----	----	----	----
G. Motor Vehicles	G.1 SO_2 scrubber/ particulate trap mufflers for all motor vehicles.	147	41	79	$5300	$4820	----
H. Aircraft Operations	H.1 a) Modification of ground operations: Towing of aircraft to avoid taxi-idle emissions (only after landing) and	1.2	.5	.6	150[b]	370[b]	
	b) Water injection for jet engines	13.6	1.9	4.1			
	total cost for a and b	14.8	2.4	4.7			$ 890
All Source Categories	All of above control measures	1650	47	235			

a. This control measure is proposed for control of particulates, NO_x and SO_2 collectively. The combined cost effectiveness of the measure for all three emission types is $505 per ton removed.

b. The cost effectiveness of particulate and SO_2 control from this measure was calculated based on (H.1.a) only because (H.1.b) has no substantial effect on particulate or SO_2 emissions.

operating cost of facilities producing fuel oil. This, of course, is possible because of the increased cost of raw petroleum stocks in the past two years relative to the cost of coal, which will be used in the production of methanol.

The conversion of fuel oils to methanol fuel in boilers and heaters is the most significant control measure contained in the plan. Sixty-two percent of the total annualized implementation cost would be accounted for by the conversion. The remainder of the cost of implementation would be due almost entirely to the motor vehicle control measure, (SO_2 scrubber/ particulate trap muffler retrofit). This measure would incur a cost of $79 million per year.

It should be recognized that the overall implementation costs shown in Table 4-12 are reflective only of the plan status in 1980. Whereas in the "Desulfurization" and "Add-on-Control" Scenarios there were no substantial cost pertubations expected in the far term, the methanol conversion of the "Delayed Scenario" would eventually (after 1980) be expected to expand to other petroleum products such as motor fuels and aircraft fuels. With engines designed to be operative on the methanol fuel, it is expected that federal emission regulations for aircraft and motor vehicles could be attained and surpassed. This occurence would virtually eliminate the need of petroleum fuels and the associated emission control equipment required to manage the pollution derived from consumption of the petroleum products. Hence the cost effectiveness and emission removal effeciency of Control Strategy III would improve in the far term, making this strategy the least costly of the alternate scenarios.

Since Control Strategy III is in harmony with national goals of energy self sufficiency, it is evident that its cost effectiveness cannot be weighed only in terms of air pollution abatement. While it is unclear how prices of methanol fuel will vary in the inflationary markets, it appears that there are important cost factors in its favor. Methanol can, for example, be produced from low quality coal, of which there are ample domestic reserves to supply the nation for many decades. In addition, it can be produced from any other carbonaceous substance which can be burned to create the required synthesis gas needed for methanol production. Eventually it is expected that methanol will be produced by chemical formation of synthesis gas, eliminating the need to consume fossil fuels. While the cost relationships for these factors cannot be assessed within the scope of this study, it is apparent that they would cause significant impact on the long term comparison of the four control scenarios considered in this study.

4.3.4 Implementation Problems

Control Strategy III is confronted with many of the same technological, socio-economic, and administrative problems associated with the first two control scenarios. (See Sections 4.1.4 and 4.2.4). The strategy is essentially the same as that of Control Strategy I except for the addition of the methanol conversion measure, which replaces the "add-on-controls" for stationary fuel combustion sources and the fuel desulfurization measures. The extent of the implementation problems due to these differences depends largely on the role of the petroleum industry in the execution of the proposed control measures. Implementation of the methanol conversion measure (B.1) would incur a substantial market loss to the petroleum industry, with even larger losses imminent with expanded future conversions for motor and aircraft fuels. Unless the petroleum industry is able to participate in the conversion measure, it would not be able to avoid severe financial setbacks imposed by the plan.

Another obvious implementation problem associated with the plan is the high capital cost of the methanol conversion measure. This measure alone will require an initial capital of $1422 million, imposing a severe funding burden on potential methanol suppliers, and raising questions as to whether governmental subsidies should be provided.

While there are numerous difficulties concerning implementation of Strategy III, there are also beneficial side effects to be derived. The plan is consistent with the nation's energy sufficiency program. Also, since it appears that methanol fuel will be cost competitive with fuel oils, there is a built-in incentive for commitment by private interests to exploit this market. Of course none of the benefits can be realized in the near term; the four to five year lead time required to construct the expensive methanol producing plant is one of the main drawbacks.

4.4 CONTROL STRATEGY IV: A DRASTIC SOURCE-RELOCATION/VMT-REDUCTION STRATEGY TO ATTAIN THE PRIMARY AIR QUALITY STANDARD BY 1980

None of the first three control strategies examined above attained the national primary standard for suspended particulates at all monitoring sites in the Los Angeles Reion. In fact, in 1980, suspended particulates at several locations are still about 25 percent above the target level for the primary standard with all three of the strategies considered. Chino, in the Western San Bernardino County Hot-Spot, still would have levels about 60 percent above the primary standard target level. It is evident that significantly more stringent controls are necessary to reach the primary standard for particulates at all locations in the Los Angeles Region.

This section describes a drastic control strategy designed to attain the primary national air quality standard for particulates. Control Strategy IV is drastic in the sense that severe "non-technological" controls have been added to the maximal technological controls as given by Strategy II. These non-technological controls include a comprehensive relocation program for all major types of stationary sources as well as a gasoline rationing program to reduce vehicle traffic by 50 percent. The socio-economic discruptions associated with this control strategy would be staggering, and it is not expected that Strategy IV would really be carried out. Accordingly, the present discussion is in some sense an academic exercise. We are investigating what type of strategy would be required to attain the national primary standard for particulates, rather than proposing a strategy for actual implementation.

The left hand side of Table 4-13 lists the control measures which are included in Strategy IV. The technological measures are identical to those in Control Strategy II, (the maximal technological control scenario). To

TABLE 4-13

CONTROL STRATEGY IV - A DRASTIC SOURCE RELOCATION/ VMT REDUCTION STRATEGY TO ATTAIN THE PRIMARY AIR QUALITY STANDARD BY 1980

NOTE: The EPA Oxidant Implementation Plan is Assumed as part of this strategy

Source Category	Proposed Control Measures for Strategy IV	Emission Reductions (tons/day)							
		1977				1980			
		Susp. Part.	SO_2	NO_x	RHC	Susp. Part.	SO_2	NO_x	RHC
MAXIMAL TECHNOLOGICAL CONTROLS									
A. Petroleum Industry	A.1 Improve efficiency of regenerator unit dust control systems from 95% to 99%, (by upgrading precipitators)	2	---	---	---	2	---	---	---
	A.2 SO_2 stack gas removal devices for catalytic crackers	---	51	---	---	---	51	---	---
B. Stationary Fuel Combustion	B.1 High efficiency baghouses applied to power plant boilers, large non-power plant boilers, and refinery heaters	67	---	---	---	64	---	---	---
	B.2 SO_2 removal systems for all refinery heaters and all oil-fired boilers	---	336	---	---	---	342	---	---
	B.3 Low excess air firing and flue gas recirculation for small power plant boilers and on large/medium size non-power plant boilers	---	---	242	---	---	---	227	---
	B.4 Low excess air firing for refinery heaters	---	---	26	---	---	---	24	---
	B.5 Water injection or exhaust gas recirculation for stationary internal combustion engines	---	---	66	---	---	---	62	---
C. Organic Solvent Use	C.1 Water wash equipment for all paint spary boths	6	---	---	---	6	---	---	---
D. Metallurgical Process	D.1 Baghouse for furnaces with uncontrolled particulate emissions	8	---	---	---	8	---	---	---
	D.2 SO_2 removal systems for all furnace effluent stacks	--	14	---	---	---	14	---	---
E. Chemical Industry		--	---	---	---	---	---	---	---
F. Minerals Industry		—	—	—	—	—	—	—	—
G. Motor Vehicles	G.1 Desulfurization of motor fuels to 100 PPM sulfur content and addition of SO_2 scrubber/particulate trap systems to all vehicles	44	44	---	---	43	44	---	---
H. Aircraft Operations	H.1 Modification of ground operations: towing aircraft to avoid taxi-idle emissions (before take-off and after landing). Also, water injection and modification of compressor air bleed rate for jet engines	5	1	15	15	7	2	23	22
Emission Reductions From the Technological Controls		132	446	349	15	130	453	336	22
NON-TECHNOLOGICAL CONTROLS									
Petroleum Refining	Relocation or the development of new technology to achieve 75% further reduction of particulate, SO_2, and NO_x emissions from the levels remaining with the above controls in 1980.	---	---	---	---	1	6	51	---
Stationary Source Fuel Combustion		—	—	—	—	16	28	237	---
Minerals Industry		---	---	---	---	9	1	---	---
Chemical Industry		---	---	---	---	8	8	---	---
Aircraft Operations		---	---	---	---	22	6	17	---
Metallurgical Processes	Relocation or the development of new technology to achieve 90% further reduction of particulate and SO_2 emissions from the levels remaining with the above controls in 1980.	---	---	---	---	5	1	---	---
Motor Vehicles	Gasoline rationing to achieve a 50% reduction in VMT in 1980. (Includes effect on RHC emissions from petroleum marketing)	---	---	---	---	10	---	332	170
Emission Reductions from the Non-Technological Controls		---	---	---	---	71	50	637	170
Total Emission Reductions for Control Strategy IV		132	446	349	15	201	503	973	192

these are added two types of non-technological controls: stationary source relocation and gasoline rationing.

Strategy IV specifies a relocation program to achieve a 75 percent emission reduction for petroleum refineries, stationary fuel combustion sources (power plants, industrial boilers, refinery heaters, etc.), mineral industries, chemical industries, and aircraft operations. In order to achieve greater improvement at the Chino location, a relocation program to attain 90 percent emission reduction is specified for metallurgical processes.* As indicated in Table 4-13, the development of new control technology to achieve the reductions is allowed as a possible option to relocation.

A 50 percent decrease in vehicle miles travelled (VMT) is also specified by Strategy IV. As indicated in Section 3.1.4, the only effective way to attain this magnitude of traffic reduction appears to be through a gasoline rationing program.

It should be noted that the severity of the relocation and gas rationing controls would be lessened by other growth, conservation, and transportation policies. In fact, we would certainly recommend that such policies be adopted along with relocation if Strategy IV were actually implemented. A no growth policy for vehicle traffic between 1975 and 1980 would reduce VMT by about 10 to 15 percent from the presently projected 1980 levels.** No growth for fuel combustion sources between 1975 and 1980 would reduce presently projected 1980 emissions by about 25 percent. However, the impact of growth policy alone (as well as of other conservation and transportation policies) falls well short of the severe emission reductions needed to attain the particulate air quality standards. Thus Control Strategy IV calls for the more stringent measures of relocation and gas rationing.

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* The Chino site appears to be strongly affected by Kaiser Steel/Edison Electric emissions.

** See Support Document #2 for projected growth rates from various sources.

4.4.1 Impact on Emission Levels

The right hand side of Table 4-13 lists the emission reductions associated with the control measures in Strategy IV. Greater total reductions are obtained in 1980 than in 1977 since the relocation and vehicle use restrictions are not to be implemented until 1980. The total emission reductions in Table 4-13 are to be subtracted from the emission projections for the EPA oxidant implementation plan which has been included as part of the strategy. The resulting emission forecasts under Control Strategy IV are given in Table 4-14. It can be seen that very strict overall control of particulate, SO_2, NO_x, and RHC emissions is attained in 1980 by the drastic measures of Strategy IV.

TABLE 4-14

EMISSION PROJECTIONS FROM CONTROL STRATEGY IV
FOR THE 4 COUNTY SUB-AREA

		PRIMARY SUSPENDED PARTICULATES			NITROGEN OXIDES		
		1972	1977	1980	1972	1977	1980
EMISSION PROJECTIONS UNDER EPA OXIDANT PLAN	(tons/day)	178	223	233	1345	1614	1434
EMISSIONS RESULTING FROM CONTROL STRATEGY IV	(tons/day)		91	32		1265	461
	(% of 1972)		51%	18%		94%	34%

		SULFUR DIOXIDE			REACTIVE HYDROCARBONS		
		1972	1977	1980	1972	1977	1980
EMISSION PROJECTIONS UNDER EPA OXIDANT PLAN	(tons/day)	444	524	535	1095	547	410
EMISSIONS RESULTING FROM CONTROL STRATEGY IV	(tons/day)		78	32		532	218
	(% of 1972)		18%	7%		49%	20%

In order to compute air quality changes at the Chino monitoring site, estimates are required of particulate and SO_2 emission reductions from the Kaiser/Edison complex. Table 4-15 presents these projections for Control Strategy IV. The very high degree of control proposed in Strategy IV for stationary source fuel combustion and for metallurgical processes brings about more than a 95 percent reduction in particulate and SO_2 levels by 1980.

TABLE 4-15

PRIMARY PARTICULATE AND SO_2 EMISSION ESTIMATES FOR THE KAISER/EDISON COMPLEX IN THE WESTERN SAN BERNARDINO COUNTY HOT-SPOT UNDER CONTROL STRATEGY IV

	EMISSION (% of 1972 LEVEL)	
	1977	1980
PRIMARY PARTICULATES	32%	4%
SO_2	15%	3%

4.4.2 Air Quality Impact

Figure 4-4 presents the impact of Control Strategy IV on suspended particulate air quality at eight locations in the Los Angeles Region. The stringent emission reductions in 1980 bring particulate levels down to at least the national primary standard target (80 $\mu g/m^3$ AAM) at each location. Five of the eight stations, (Lennox, Long Beach, Downtown, Anaheim, and Ontario), also attain the national secondary standard target level, (65 $\mu g/m^3$ AAM). The other three stations, (Asuza, Riverside, and Chino), are right at or just below 80 $\mu g/m^3$ AAM.

With the severe emission reductions of Strategy IV, the air quality levels at each location approach background levels. The differences in

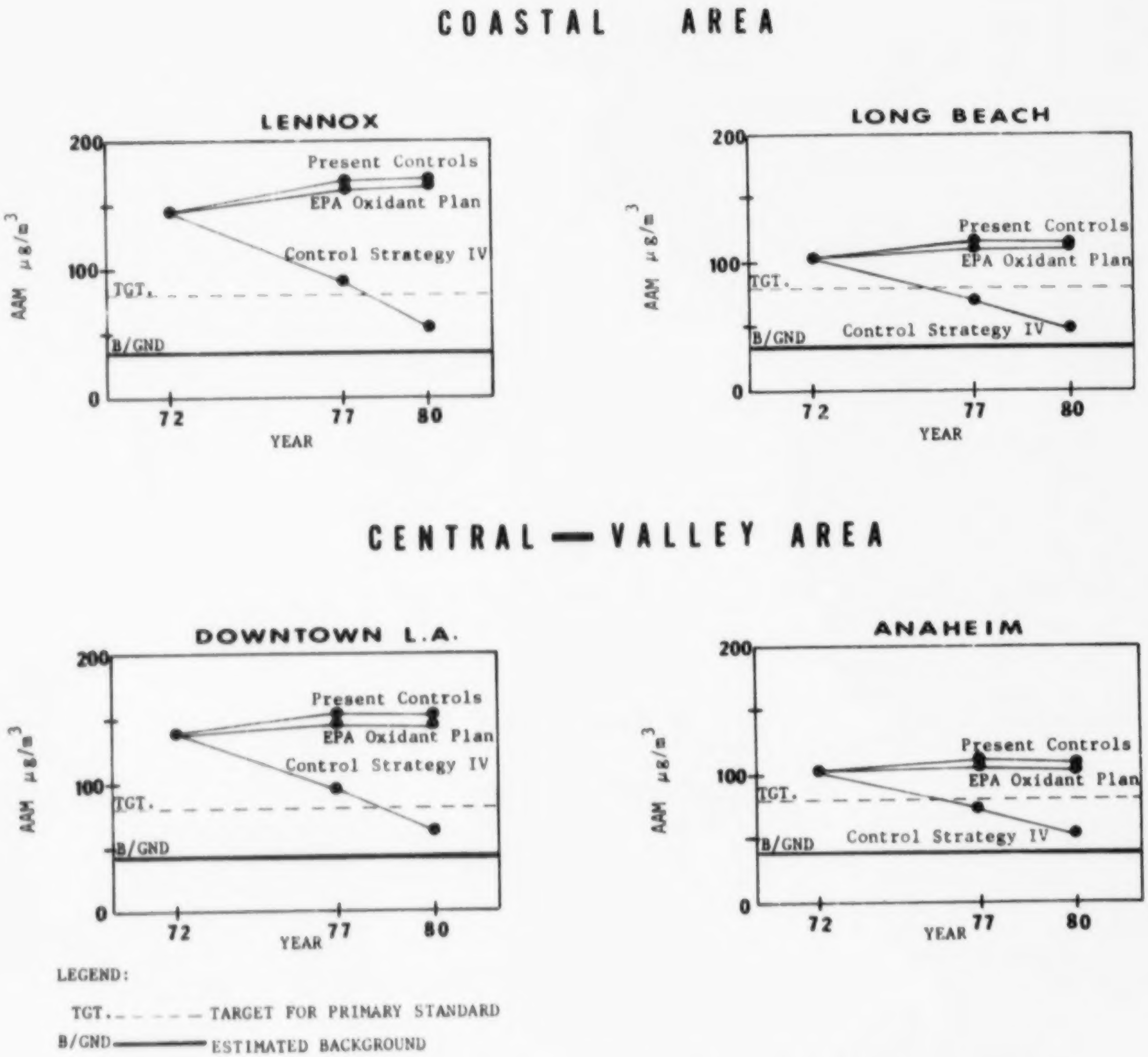

Figure 4-4 Air Quality Impact of Control Strategy IV on Suspended Particulate Levels in the Los Angeles Region

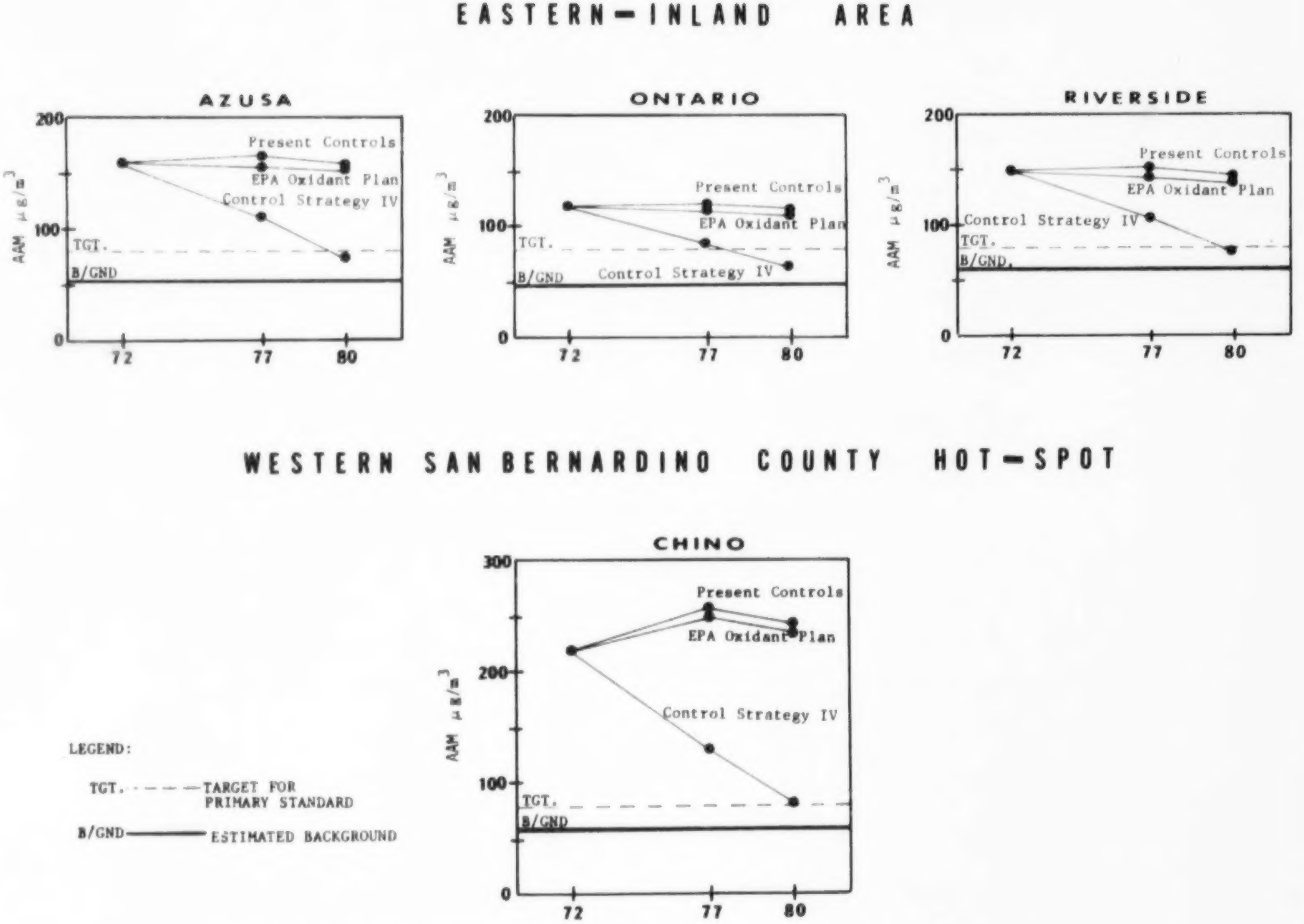

Figure 4-4 Air Quality Impact of Control Strategy IV on Suspended Particulate Levels in the Los Angeles Region (Continued)

air quality at the various locations are then dominated by the relative background levels. The basic reason why Asuza, Riverside, and Chino attain only the primary standard while the other stations attain the secondary standard is that the former three locations have the highest estimated background levels, (53 to 60 $\mu g/m^3$). As noted previously, these high background* levels are the principal reason why very stringent control is needed to attain the primary standard.

4.4.3 Control Costs

Control Strategy IV combines the high costs of the Maximal Technological Control Strategy with prohibitive costs of drastic administrative controls. The cost of the relocation measure, requiring the major industries to relocate 75 percent of their emission sources or to provide new technology to control these emissions an equivalent degree, is probably insurmountable.** It is not clear which cost would be greater, the development of new control technology or relocation. If current control technology were used to comply with the measure, the cost of implementation could conceivably exceed the capital worth of the industrial facilities themselves. Relocation would, in many cases, impose similar costs. Quantitatively assessing the impact of these costs which would undoubtedly force many concerns out of business, is beyond the scope of this study.

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*The reader should note that background refers to non-controllable origin categories in this report. These origin categories include suspended soil dust from man-made activities and man-made sources exterior to the Los Angeles Region as well as natural sources.

**The reader is reminded that a 75% further reduction is required from the "maximal technological control" level.

4.4.4 Implementation Problems

Because of the severe socio-economic disruptions which would be imposed by Control Strategy IV, it is considered unimplementable. It is unlikely that the extreme costs imposed on industrial interests could be recovered unless massive subsidies were incorporated in the plan. While resistance from influential firms would pose great implementation problems, strong resistance would also be generated from the general public. Personal livelihoods would be threatened and life styles would be severely disrupted. These impacts would be difficult to predict or measure and are not within the evaluative scope of this report. Suffice it to say that total attainment of the particulate air quality standards in Los Angeles is not implementable within the modus operandi of the prevailing political and socio-economic framework.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations which have resulted from the various phases of this investigation. Section 5.1 deals with proposed control strategies. The four alternative control scenarios are compared and recommendations are made as to preferred strategies. Section 5.2 summarizes the conclusions reached by the technical support analyses performed in the study. The limitations of these analyses are discussed and recommendations are made for further research efforts.

5.1 CONTROL STRATEGY RECOMMENDATIONS

The previous chapter formulated and evaluated alternative control strategies designed to reduce suspended particulate levels in the Los Angeles Region. These strategies consisted of various combinations of emission control measures for primary particulates and for gaseous precursors of secondary particulates. The evaluation included analyses of emissions reductions, air quality impacts, control costs, and implementation problems. Table 5-1 summarizes the overall air quality improvement, economic costs, and implementation difficulties associated with each of the strategies.

As noted in the previous chapter, Control Strategy IV (the air quality standard attainment strategy for 1980) is not considered implementable. As indicated in Table 5-1, this strategy would involve great socio-economic disruption; its implementation would be oppossed by very strong public and private forces. We do not think that Strategy IV would serve as a viable approach to particulate air quality policy in the Los Angeles Region, and we do not recommend it as a policy goal.

An overall comparison of Strategies I and II, (Table 5-1), reveals that Strategy II (maximal technological control) achieves small air quality improvements over Strategy I (reasonable/implementable scenario) at the expense of extra economic costs and more difficult implementation problems. A recommendation of one of these strategies over the other should be based on a comparison of the marginal reductions in pollution damage costs vs. the marginal increases in control and administrative costs. The quantitative analysis required to make this comparison is not within the scope of the present effort. However, through a qualitative examination of the problem we have concluded that Strategy I appears preferable to Strategy II. The relative air quality improvement in Strategy II, (about 3 to 4%), does not seem to compensate for the extra costs and implementation problems associated with that strategy.

A comparison of Strategy II with Strategy III reveals that both plans attain the same overall air quality level by 1980. However, the delayed scenario based on methanol conversion (Strategy III) achieves much less air quality improvement by 1977. Although the delayed methanol strategy has higher capital cost, it demonstrates lower total annualized cost than Strategy II. A recommendation concerning Strategy II vs. Strategy III should be based on a comparison of the benefits of the earlier air quality improvements (Strategy II) to the lesser total annualized cost (Strategy III). A quantitative analysis of this problem is not possible within the level of effort allocated to this study. However, by a cursory analysis of the problem, we find a distinct preference for Strategy III. Strategy III has appeal because of substantial side benefits for national energy problems. Further, Strategy III is preferable because it

TABLE 5-1

SUMMARY OF AIR QUALITY IMPACTS, CONTROL COSTS, AND IMPLEMENTATION PROBLEMS ASSOCIATED WITH THE ALTERNATIVE CONTROL STRATEGIES

	AIR QUALITY FORECAST				CONTROL COSTS[b]			IMPLEMENTATION DIFFICULTIES
	Average AAM at the 4-worst stations (Chino, Azusa, Riverside, & Lennox) 1972 Level = 169 µg/m^3		Number of stations which attain the primary national standard target level. (Out of the 8 sites studied)[a] 1972 Level = 0		Initial Capital Cost (Millions)	Total Operation Cost (Millions/year	Total Annualized Cost (Millions/year)	Relative level of Implementation Problems on a scale of 1 to 10. 1 = Difficult 10 = Extremely Difficult
	1977	1980	1977	1980				
Present Control Emission Forecast	187 µg/m^3	180 µg/m^3	0	0				
EPA Oxidant Plan Emission Forecast	179 µg/m^3	174 µg/m^3	0	0				
Control Strategy I: A Reasonable/Implementable Scenario for 1977 and 1980. (The Desulfurization Scenario)	117 µg/m^3	112 µg/m^3	2	2	$ 896	$ 119	$ 226	1
Control Strategy II: Maximal Technological Control by 1977	110 µg/m^3	108 µg/m^3	2	2	$1211	$ 206	$ 367	2
Control Strategy III: A Delayed Scenario for 1980 based on Methanol Conversion	152 µg/m^3	108 µg/m^3	0	2	$1650	$ 47	$ 235	2
Control Strategy IV: A Drastic Source Relocation/VMT Reduction Strategy to Attain the Primary Standard by 1980	110 µg/m^3	72 µg/m^3	2	8	Undetermined[c]	Undetermined[c]	Undetermined[c]	10

a. These eight sites are not typical locations but rather are among those with the highest particulate levels.

b. These costs are in addition to the present controls and the EPA oxidant plan which are assumed as part of each strategy.

c. These costs would be at least as great as Strategy II which is included in Strategy IV. They might actually be orders of magnitude more.

is the best long run plan. Particulate air pollution will be a long term problem for the Los Angeles Region, and we consider long term strategies to have distinct advantages over shorter term plans.

To summarize, the reasonable/implementable and the delayed methanol conversion scenarios are the preferred plans among the four strategies formulated here. Choosing between these two strategies is difficult. The two plans result in nearly the same total annualized cost. Strategy I leads to significantly better air quality in 1977 but to slightly worse air quality in 1980. Strategy III requires more capital investment and involves considerably more implementation obstacles. However, as noted above, Strategy III has beneficial side-effects for the national energy problem and is very attractive on a long-term basis. All in all, we find a slight preference for Strategy III because of the long-term advantages. The major factor which is of concern with Strategy III is the implementation problem which will be encountered, (see Section 4.3.3).

Several of the control measures in Strategies I and III are identical, (See Tables 4-1 and 4-9). For these measures we recommend that steps be taken for actual implementation. These steps should include an in-depth analysis of each measure to prepare for possible engineering, administrative, or legal problems. For the areas where Strategies I and III diverge, (essentially fuel desulfurization plus stack controls vs. methanol conversion), it is recommended that further comparative analysis be done, especially in the area of implementation obstacles. This will allow a more confident choice to be made between the two alternatives. Steps can then be taken to implement the appropriate strategy.

A control policy based on either Strategy I or Strategy III should also include some non-technological controls such as growth restrictions, energy conservation incentives, transportation measures, and possibly some relocation. These administrative controls will be particularly important in the long run. It was not possible in this study to perform a quantitative analysis of non-technological controls. Strategy IV indicated the overall level of administrative control that would be needed to attain the air quality standards by 1980. However, this very severe level of control would require extensive source relocation and gas rationing. We recommend that more moderate forms of administrative control be documented and that these be included in a comprehensive air quality policy.

It should be remembered that the above control strategies have been formulated and evaluated for the 4 County Area of the Metropolitan Los Angeles Region. The remainder of the Los Angeles Region, Ventura and Santa Barbara Counties, experiences a much less severe particulate air pollution problem. Presently, the suspended particulate levels in Ventura and Santa Barbara Counties are just above the national primary standard. Either Strategy I or Strategy III would attain the national primary standard (and possibly the national secondary standard) when applied to the Ventura/Santa Barbara area. However, since the origin of the particulate problem in these two counties is apparantly different, (mineral industries and agriculture are much more important than in the 4-County Area), it is recommended that a separate examination be made of the particulate control problem for Ventura and Santa Barbara. It should be possible to pick a different strategy for Ventura and Santa Barbara that would involve lower costs and less implementation problems. The examination of control strategies for these counties might best be carried out by local control agencies who are familiar with the important stationary source problems.

In order to be consistent with the present form of the national air quality standards for suspended particulates, the air quality evaluation of the above strategies has been done only on the basis of total mass concentration of suspended particulates, ($\mu g/m^3$). As noted in Section 1.2, (Limitations in the Scope of the Study), the chemical composition of suspended particulates is very important to health effects. In the future, air quality standards may be expected for certain aerosol constituents. Sulfate aerosol is of particular concern in this respect. Since the air quality model used here inherently includes calculations of sulfate levels, it may be useful to indicate the effect of the two recommended strategies on sulfate levels. Table 5-2 provides estimates of sulfate air quality for each of the strategies. These results should be interpreted with caution. As noted in Section 2.3.2, the air quality model tends to be especially uncertain when used to predict individual secondary aerosol components such as sulfates, nitrates, and secondary organics.

Section 1.2 also noted that particle size distribution is important to health and visibility considerations. Particles in the .1 to 1 micron range are especially significant. In this regard, we can add an optimistic note. The strategies here have been formulated for man-made primary suspended particulates (less than 10 microns in size) and for man-made sources of secondary aerosol. These man-made sources are the major contributors of aerosol in the smaller size range, (<1 micron). The greatest

TABLE 5-2 SULFATE AIR QUALITY IMPACT OF THE RECOMMENDED STRATEGIES[a]

($\mu g/m^3$ - AAM)

Location	Estimated $SO_4^=$ Background	Expected 1972 $SO_4^=$ Levels	Strategy I $SO_4^=$ Levels		Strategy III $SO_4^=$ Levels	
			1977	1980	1977	1980
Lennox	4	13	8 ½	6	12 ½	5
Long Beach	4	11	7 ½	5 ½	10 ½	4 ½
Central Los Angeles	4	14	9	6	13 ½	5
Anaheim	4	9	6 ½	5	8 ½	4 ½
Azusa	4	15	9 ½	6	14	5
Ontario	4	10	7	5	9 ½	4 ½
Riverside	4	12	8	5 ½	11 ½	5
Chino[b]	4	22	13	8 ½	22 ½	5 ½

a. These results have been computed using the linear $SO_4^= / SO_2$ model outlined in Section 2.3.2. As noted there and in Support Document #3, the linear model probably tends to underestimate resulting sulfate levels. As indicated in the support document, the calculated controlled values in this table are likely about 1 $\mu g/m^3$ low, with the maximal error possibly as much as 3 $\mu g/m^3$. The uncertainties in the linear model should be kept in mind in interpreting these results.

b. The calculation for Chino is performed in a specialized way as outlined in Section 2.3.3. The local Kaiser/Edison contribution is computed separately.

portion of the natural aerosol, (sea salt and soil dust), occurs predominately in the larger size range (<1 micron), [93]. When a given percent of control is suspended particulate air quality is indicated in this report, this control tends to occur among the sources of the smaller particles. The relative reduction in mass loading of the smaller particles will likely be greater than the relative reduction in total mass loading. Thus, one would expect more improvement in visibility and health than indicated by the calculated improvements in total mass loading.

5.2 CONCLUSIONS AND RECOMMENDATIONS RESULTING FROM THE TECHNICAL SUPPORT ANALYSES

The principal goal of this study was to investigate control strategies for approaching and achieving the National Ambient Air Quality Standards for suspended particulates in the Metropolitan Los Angeles Region. In order to perform a systematic investigation, four major technical support analyses were conducted. These were (1) an analysis of particulate air monitoring procedures and a characterization of present air quality levels in the Los Angeles Region, (2) a compilation of emission inventories and projections for both primary particulates and gaseous precursors of secondary particulates, (3) the development of a methodology to translate changes in emission levels into changes in air quality, and (4) an identification and evaluation of alternative emission control measures for major sources of both primary particulates and gaseous precursors of secondary aerosol. These analyses are described in detail in Technical Support Documents #1-#4. Chapters 2 and 3 of this report are condensed versions of the support documents.

This section serves to summarize the major conclusions and recommendations which resulted from the technical support analyses. This summary includes some discussion of analytical limitations and of needs for future work. Each of the four technical areas is treated in turn below.

Analysis of Air Monitoring Data

Conclusions:

- Hi-Vol filters generally provide a very efficient means of entrapping samples of suspended particulate matter. However, samples are not always fully representative of ambient conditions due to loss of volatile liquids (such as water or organics) and/or gain of adsorbed gaseous pollutants(such as SO_2 or NO_2). Hi-Vol data do not provide information on particle size distribution.
- Specific monitoring practices can significantly affect Hi-Vol accuracy. Substantially different practices can produce discrepancies on the order of 20%. The reproducibility of individual Hi-Vol measurements using equivalent procedures is around 5% under field conditions.
- The APCD, NASN, and CHESS monitoring programs generally follow the same sampling guidelines. However, deviations exist in certain specific practices such as sampling frequency, calibration procedures, flow rate, analysis delay time, and location. In some cases, these deviations are enough to cause significant differences in measured values.
- The 6 CHESS sites in the Los Angeles Region are located in quiet suburban areas. Measurements from CHESS monitors are generally around 20-40% lower than those from APCD and NASN sites which tend to be in prime exposure urban areas.
- The western part of the basin, near the coast, tends to experience the highest Hi-Vol levels during the winter season. In the eastern part of the basin, the summer/fall period tends to yield the highest Hi-Vol readings. These findings appear to be consistent with the hypothesis that primary particulate (directly emitted) is relatively more important in the western basin while secondary particulate (formed by atmospheric reactions) is relatively more important in the eastern areas.
- The federal secondary air quality standards are exceeded at all monitoring sites which were analyzed. Ventura and Santa Barbara Counties as well as the coastal areas of Los Angeles and Orange Counties typically yield Hi-Vol levels at just about the federal primary standards. Riverside and San Bernardino Counties and the inland areas of Los Angeles and Orange Counties yeild Hi-Vol values up to more than twice the federal primary standards.

- In the inland areas of greatest particulate pollution, no general pattern can be discerned in Hi-Vol measurements with the present level of spatial resolution. The location of each monitoring site with respect to local sources appears to be important; this effect produces fluctuations so that no general pattern emerges.

Recommendations:

- It would be useful to perform experimental studies to gain further information on the differences between Hi-Vol measured particulates and actual ambient particulates. These studies should focus on quantifying the loss of water and volatile organics and the gain of adsorbed gaseous pollutants under actual field conditions.
- A further standardization of Hi-Vol procedures among various monitoring programs is recommended. The establishment of guidelines for site location with respect to local sources is particularly important. This standardization could afford more meaningful comparisons of data from alternative monitoring programs.
- The establishment of an ongoing program of data analysis would allow better use to be made of the considerable quantities of Hi-Vol data being generated in the Los Angeles Region. Such a program should continually examine trends in total suspended particulate levels and in specific aerosol constituents and should compare these results with the expected impact of source growth and emission control policy.
- For the purpose of control strategy formulation, at least three general sub-areas have been identified, each with different maximal Hi-Vol levels (the maximum among the monitoring sites in those areas). These are A. Ventura and Santa Barbara Counties (presently just above the national primary standard), B. The 4 County Area except Area C (presently at about twice the national primary standard), and C. The Western San Bernardino County Hot-Spot (presently at about three times the national primary standard). The formulation and evaluation of control strategies should make distinctions among these three areas.

Emission Inventories and Projections

Conclusions:

- Numerous alternative data sources are available for compiling the 1972 base year inventory of primary suspended particulates, SO_2, NO_x, and RHC for the Los Angeles Region. Conflict often exists among the varous data sources; this is an indication of the uncertainties in emission data. Presently, the most appropriate way to construct an emission inventory for implementation planning is to use many sources of data, picking the most reliable sources for each inventory category.

- Data are not available for compiling an RHC inventory based on the aerasol forming potential of organic gases. For the purposes of this study, an RHC inventory based on oxidant reactivity seems more appropriate than a total hydrocarbon inventory.

- The size distribution of particulate emissions from various sources is not well documented. However, estimates of the fraction of particles below 10 microns for various sources are available so that suspended particulate emissions can be distinguished in an approximate way from total particulate emissions.

- Motor vehicles are the major source of RHC and NO_x emissions in the 1972 base year inventory for the Los Angeles Region. Motor vehicles and stationary source fuel combustion account for most of the suspended particulate emissions. Stationary fuel combustion, the chemical industry, petroleum refineries, and motor vehicles are respectively the most important sources of SO_2.

- The forecasted substitution of fuel oil for natural gas in many stationary combustion sources and the scheduled controls for motor vehicles are the two most significant factors affecting emission projections for 1977 and 1980 in the Los Angeles Region. Due to the increased use of fuel oil, total emissions of suspended particulates, SO_2, and NO_x will increase from 1972 to 1977 with present control policies. The motor vehicle control program will significantly reduce regional RHC emissions in 1977 and 1980; it will also reverse the upward trend in NO_x emissions, (leading to a decrease between 1977 and 1980). Stationary combustion will be the largest single source of suspended particulates and SO_2 in 1980 and will nearly equal motor vehicles as an NO_x contributor.

- The EPA oxidant implementation plan results in significantly lower RHC emissions than present control policy. The EPA oxidant plan also achieves very slight reductions in particulate and SO_2 emissions. However, the catalytic converter retrofit called for by the EPA plan, (as well as the new car catalytic converters), will result in the emission of sulfuric acid mist from motor vehicles. The latter can be controlled by desulfurization of motor fuels or by SO_2 scrubber/particulate trap retrofits.

- Large scale emission density maps reveal that RHC, NO_x, and (to some extent) particulate emissions are distributed in a way similar to population and motor vehicle traffic within the Los Angeles Region. An emission density map for SO_2 indicates the importance of very localized sources for that pollutant.

Recommendations:

- Efforts to update emission information for both mobile and stationary sources should be supported. Further documentation is needed to reduce uncertainties concerning both source growth rates and source emission factors.

- Of special importance to particulate air quality studies is the need for RHC emission inventories based on the aerosol forming reactivity of organic gases. Also of importance is information on the size distribution of particulates from various sources. Further effort should be made to generate data pertinent to these two issues.

- The severe air pollution problem in the Los Angeles Region will be significantly aggravated by the forecasted substitution of fuel oil for natural gas in many stationary combustion sources. It is recommended that national allocation of clean fuels, such as natural gas, be performed with strong consideration given to air quality impacts in various regions.

The Relationship Between Emissions and Ambient Air Quality

Conclusions:

- In order to construct a systematic relationship between suspended particulate levels and emissions of primary particulates, SO_2, NO_x, and RHC, two separate analyses must be performed. The first is to characterize the origins (e.g., background, non-background primary, non-background sulfate, etc.) of suspended particulate levels at various locations. The second is to determine the dependence of each origin category on emission levels.

- Existing aerosol composition data (from the county APCD's, NASN, and other monitoring programs) are sufficient to support an approximate aerosol origin characterization for annual arithmetic means (AAM'S) at twelve locations in the Los Angeles Region. Existing data are not sufficient to characterize aerosol origins on episode days. The latter result may not be a severe handicap to control policy formulation since it appears that the annual national standards for particulates are more restrictive than the 24 hour max. national standards in the Los Angeles Region.

- Existing data indicate that background (non-controllable) particulate levels are about 30-40 $\mu g/m^3$ AAM in the coastal areas of the Los Angeles Region. Background aerosol levels appear to increase with distance inland to about 45-60 $\mu g/m^3$ AAM in the eastern-inland parts of the region. The existence of significant background levels limits the air quality effectiveness of emission controls in the Los Angeles Region.

- Non-background primary particulate contributions generally tend to be highest in the coastal and central-valley portions of the Los Angeles Region. The one exception involves the very high primary contributions estimated for the Western San Bernardino County Hot-Spot (Chino-Rialto) which is apparently affected by the Kaiser/Edison complex. Sulfate levels tend to be uniformly distributed over the basin at around 10-15 $\mu g/m^3$ AAM, (again the Hot-Spot is an exception). Measured nitrate and estimated secondary organic levels tend to increase considerably with distance inland. The above spatial trends appear to be consistent with known aspects of source distribution, meteorology, and atmospheric chemistry.

- For the purposes of this study, the linear rollback formula appears to be generally adequate for relating primary suspended particulate emissions to non-background primary aerosol levels. In order to assess air quality changes for the special case of the Western San Bernardino County Hot-Spot, a modification of the linear rollback approach must be made.

- Considerable uncertainty surrounds the relationship between non-background sulfate air quality and SO_2 emissions. However, theoretical analysis and empirial data both suggest a slightly less than linear dependence. At low SO_2 levels, sulfate yield appears to increase linearly with SO_2 input. At higher SO_2 levels, the sulfate yield tends to level off. For the purpose of this study, (the prediction of total suspended particulate levels), it appears sufficient to assume a linear relationship.

- Very little is known concerning the dependence of nitrate levels on NO_x emissions and the dependence of secondary organic levels on RHC emissions. In this study a simple linear form is assumed for each relationship. The main justification is that there is no evidence to support the use of any specific nonlinear relationship.

Recommendations:

- In order to improve the aerosol origin estimates, more comprehensive data are needed on particulate chemical composition. Specifically, it is recommended that further sodium and aluminum data be taken to verify the sea salt and soil dust levels calculated here. Also, it would be very useful to devise and apply a method for measuring secondary organic particulate levels. Existing data on ambient organic aerosol, (benzene or cyclohexane solubles), are essentially only measures of primary organic contributions.

- Further research effort should be allocated to determining the the dependence of secondary aerosol levels on gaseous precursor emissions. Much of the research to date has been directed toward identifying the reaction mechanisms and understanding the physico-chemical processes. This work should be continued since it supplies a scientific base for explaining the relationship. However, it may be possible to obtain reasonable answers in a shorter time by emphasizing an empirical approach. Ambient and experimental measurements of NO_x (or SO_2) input vs. nitrate (or sulfate) yield may be able to supply a relationship that is adequate for present planning purposes.

Evaluation of Alternative Emission Control Measures

Conculsions:

- Eight process categories are the major candidates for control in the Los Angeles Region. These are stationary source fuel combustion, motor vehicles, the petroleum industry, aircraft, the chemical industry, metallurgical processes, organic solvent use, and the mineral industry. Together these categories account for more than 97 percent of the emissions of primary particulates, SO_2, NO_x, and RHC in the Los Angeles Region. Especially significant are the fuel combustion, motor vehicle, petroleum, and aircraft categories.

- The federal and state motor vehicle control programs and the county APCD stationary source control programs have achieved substantial overall control for primary particulates and gaseous precursors of secondary aerosol in the Los Angeles Region. However, additional control options can be identified to bring significant further reductions in emissions.

- The most significant additional control alternatives for primary suspended particulates in the Los Angeles Region are motor vehicle particulate traps, fabric filters, and electrostatic precipitators. For SO_2, the major options are desulfurization of petroleum products to very low sulfur levels, SO_2 removal processes for exit gases, and alternative fuels. For NO_x control, various modifications of combustion processes and alternative fuels are the principal control possibilities. No major new options for RHC control, other than those contained in the EPA oxidant implementation plan, have been identified.

- Application of the most effective control options which have been identified will attain overall reductions of 59 percent, 86 percent, and 22 percent (for primary suspended particulates, SO_2 and NO_x respectively) from projected 1977 levels. Since emissions of each pollutant are forecasted to increase from 1972 to 1977, the overall reductions in 1977 from the 1972 levels are only 49 percent, 83 percent, and 6 percent respectively. The EPA oxidant plan will achieve a 51 percent reduction in RHC levels from 1972 to 1977.

- The total annualized cost associated with a major new control program to achieve substantial emission reductions such as that noted above would be around $300 million per year. The initial capital cost would be around $1 billion. These costs would be in addition to the costs of present controls and the costs associated with the EPA oxidant plan.

- The various control measures for each pollutant demonstrate a wide range of cost-effectiveness. Most of the suspended particulate controls yield cost effectiveness ratios around $1,000 to $7,000 per ton. The majority of the SO_2 controls considered here had cost-effectiveness values of around $500 = $1500 per ton. Most

NO_x measures tended to demonstrate ratios of around \$500 - \$1200 per ton controlled.

- Many of the potential control measures will entail significant implementation difficulties. These will include problems of technical development, engineering application, enforcement, and administration.

Recommendations:

- As control strategy planning efforts proceed, more in-depth analysis should be performed on the effectiveness and cost of the control measures studied in this report. Due to limitations on time and level of effort, the present study estimated control efficiency and costs on a simplified basis, aggregating over many emission sources in a given process category. The cost and effectiveness of the measures will likely vary substantially among individual sources within a given process category. Some of these variations can have significant implications for control policy.
- As part of the implementation procedure, proposed control measures should undergo an intensive evaluation as to real applicability. This evaluation should be carried out by a task force of industrial, academic, and governmental experts who would consider the specific engineering, enforcement, and legal problems involved with the control measure. A carefully planned and executed implementation procedure should help to reduce technical difficulties as well as public and private resistance.
- Further attention should be given to a long tern view of the various control measures. A strategy based on long run considerations may be considerably different from one designed to achieve short run control. Short run controls should be evaluated as to their compatibility with likely long run controls.

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